Four Essays Investigating the U.S. Subprime Mortgage-Backed Securities Market

By

Lisa Sheenan B.A., M.A.

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National University of Ireland Maynooth (NUIM),

Maynooth, Co. Kildare, Ireland.

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Supervisor: Dr. Thomas J. Flavin B.B.S., M.A., D. Phil (University of York),

Department of Economics, Finance & Accounting,

National University of Ireland Maynooth.

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Summary

The U.S. subprime mortgage-backed securities market has attracted intense attention during and after the widespread financial turmoil of 2007-2009. Most commentators have reached a consensus that an underestimation of the risks associated with these products led to problems for the entire financial system. Therefore, this thesis seeks to provide a better understanding of these complex financial instruments and their role in the propagation of the crisis.

We focus on three main issues. The first issue (Chapter 3) analyses the risk factors underlying this market. The goal is to identify key variables that may potentially explain its decline. Measures of the U.S. real estate market, interbank liquidity and counterparty risk, as well as market volatility are all found to play a role. Furthermore, we find that the importance of these risk factors changed as the crisis evolved from a real estate problem to a broader global credit crisis.

The second issue (Chapter 4) concerns identifying interdependencies and contagion within this market during the crisis. We adapt the vector autoregressive (VAR) framework of Longstaff (2010) to estimate the intra-market relationships using a spliced ABX dataset and two traded ABX vintages. We find contagious effects during the subprime crisis, emanating mainly from shocks to the higher-rated assets.

Finally, the third issue (Chapters 5 & 6) examines contagion from the subprime mortgage-backed securities market to several other asset markets using both the original and an extended version of Longstaff's (2010) VAR framework. Using the original specification, evidence of contagion is found but we uncover important differences between the choice of index used to proxy for the subprime mortgage-backed securities

market. Furthermore, employing a more innovative econometric tool, namely a time-varying transition probability Markov-switching VAR, shows that although contagion played a role in transmitting the shock to other markets, it may not have been as prevalent as suggested by the original VAR framework. We conclude that accurately dating the crisis is crucial to the analysis.

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Conferences

I have presented **Chapter 3** titled *"Identifying Risk Factors Underlying the U.S. Subprime Mortgage-Backed Securities Market"* at the *Money Macro and Finance Group* at its 44th Annual Conference in County Dublin, at the parallel session: "Empirical Analysis of Risk Premia" (2012). Chapter 3 has also been presented at the *Irish Society of New Economists* at its 9th Annual Conference in County Cork, at the parallel section: "Finance" (2012). Earlier versions of this chapter have been presented at NUIM *Department of Economics Internal Seminars* (2011) and at *NUIM PhD Internal Seminars* (2011).

I have presented **Chapter 4** titled *"Analysing Contagion Within the U.S. Subprime Mortgage-Backed Securities Market"* at the *Irish Society of New Economists* at its 10th Annual Conference in County Kildare, at the parallel section: "Finance" (2013). Chapter 4 has also been presented at the *Money Macro and Finance Group* at its 45th Annual Conference in London, at the parallel session: "Banking Crises" (2013) and at the *Irish Economic Association* at its 27th Annual Conference in county Kildare, at the parallel section: "Asset Markets" (2013). Earlier versions of this chapter have been presented at NUIM *Department of Economics Internal Seminars* (2012) and at *NUIM PhD Internal Seminars* (2012).

I have presented **Chapter 6** titled *"A Regime Switching Analysis of Contagion From the U.S. Subprime Mortgage-Backed Securities Market"* at *NUIM Department of Economics Internal Seminars* (2013). Chapter 6 has also been accepted for presentation at the *Irish Economic Association* at its 28th Annual Conference in county Limerick at the parallel session: "'Financial Economics" (2014) and the *International Banking and Finance Society* at its 6th Annual Conference in Lisbon (2014). Earlier versions of this chapter have been presented at a Central Bank of Ireland *Financial Stability Division Internal Seminar* (2014).

Chapter 1

Introduction

This thesis contains four essays examining various aspects of the financial crisis of 2007-2009 by focusing on the widely cited source of the problem, the United States' subprime mortgage-backed securities market. In order to do so the ABX.HE indexes are employed to represent this market and so these are the focus of this study. This thesis analyses three issues in relation to this market's role in the crisis. The issues examined include an empirical examination of the risk underlying this market; an analysis of contagion within this market; and finally an investigation of contagion from this market to other financial markets during the crisis.

Chapter 2 provides a comprehensive overview of the crisis and the role that subprime mortgage-backed securities played in it while the subsequent four chapters all involve empirical analysis of the ABX.HE indexes. Principal component analysis (PCA) is employed in Chapter 3 in order to reduce the dimensionality of noisy ABX returns and uncover common driving factors. OLS regression and rolling regression analyses are also used to trace the evolution of the crisis from a real estate problem to a much broader global credit crisis. Several vector autoregressive (VAR) analyses are estimated throughout the thesis to test for contagion as a significant increase in market linkages following a shock, e.g. a traditional VAR model (Chapter 4), a VAR model with dummy variables included to account for crisis periods (Chapter 5) and a time-varying transition probability Markov switching VAR (Chapter 6). The VAR models employed in Chapters 4 and 5 allow us to test for contagion under a framework in which crisis and non-crisis regimes are exogenously selected while the VAR employed in Chapter 6 enables regimes to be determined endogenously by the data.

The thesis is structured as follows:

Chapter 2 provides a comprehensive overview of the financial crisis of 2007-2009, discusses the subprime mortgage-backed credit derivatives that were its focal point and describes the ABX indexes, traded credit indexes backed by U.S. subprime mortgages that are empirically analysed throughout this thesis. These indexes provide the only available proxy for the distressed asset-backed security market and there is a growing literature analysing their role in the crisis and their underlying risk factors (such as Dungey, Dwyer & Flavin, 2013; Fender & Scheicher, 2008; Gorton, 2009; and Mizrach, 2011).

Chapter 3 investigates the risk underlying the ABX indexes, an important issue as it became clear in the aftermath of the crisis that, in the majority of cases, this risk had been grossly underestimated, leading these products to be mispriced and precipitating the crisis. Prior empirical research in this area reports that risk factors affecting the indexes changed over the evolution of the crisis and highlights the heterogeneous nature of ABX vintages, as well as differences across the ratings tranches comprising these securities (Dungey, Dwyer & Flavin, 2013; Fender & Scheicher, 2008). Preliminary OLS regression analysis indicates that house prices are the main driver of variation in ABX returns over the sample period. However, as related literature (Brunnermeier, 2008; Gorton, 2009) suggests that other factors had a role to play in the crisis, principal component analysis (PCA) is performed on the ABX returns to reduce the dimensionality of such a noisy data set and uncover the common factors driving the variation in the ABX. The results suggest that commonality fell across vintages (consistent with findings by Fender & Scheicher, 2008), suggesting that they are unique, distinct assets (as suggested by Dungey, Dwyer & Flavin, 2013). The main principal component is then included in further OLS regression analysis in place of ABX returns in an attempt to obtain clearer results. The results show that factors other than house prices, such as liquidity and counterparty risk, drive ABX returns during the sample period. To examine the behaviour of the regression coefficients over time a rolling regression analysis is then employed, the results of which suggest that, over the evolution of the crisis, concerns regarding house prices became overshadowed by concerns regarding liquidity and counterparty risk (as suggested by Brunnermeier, 2008).

Chapter 4 analyses contagion within the ABX indexes in a further effort to understand these complex securities. To date there exists no prior empirical work addressing this question, although Longstaff (2010) tests for contagion from the ABX to other financial markets during the crisis. Chapter 4, along with Chapters 5 and 6, therefore treats Longstaff (2010) as the benchmark test for contagion during the recent crisis. The spliced ABX index of Longstaff (2010) is analysed, along with two traded ABX vintages, using a VAR framework. The results indicate evidence of contagion within the three ABX series analysed during the 2007 "subprime-crisis" period, which then dissipates in the 2008 "global-crisis" period as markets suffered the liquidity freeze, before increasing slightly during the 2009 "post-crisis" period, as markets rebounded following the crisis. The sum of lagged coefficients indicate that persistent shocks emanate from the higher-rated assets in the traded vintages but from the lower-rated assets in the spliced ABX, indicating that splicing the data may affect results.

Chapter 5 analyses contagion from the ABX to several fixed income, equity and volatility markets following Longstaff (2010). Contagion during a catastrophic crisis such as that experienced in 2007-2009 is clearly of importance to both investors and institutions and there is a growing literature testing for its presence during the recent crisis. Empirical analysis has found evidence of contagion, during the subprime crisis, in the interbank markets of both emerging and developing countries and the capital markets of developed countries (Abbassi & Aschnabel, 2009; Hwang, In & Kim, 2010; Horta, Mendes & Vieira, 2008). As yet, only Longstaff (2010) uses the ABX to test for contagion during the crisis so Chapter 5 applies his VAR framework to two traded vintages to test for contagion to other asset markets during the crisis. Evidence of contagion is found, but results differ across ABX assets. One limitation of the methodology presented in Longstaff (2010) is that crisis regimes are imposed exogenously on the data. The subsequent chapter therefore attempts to address this issue.

Chapter 6 also investigates contagion from the ABX to asset markets during the crisis, by extending the methodology of Chapter 5. To allow regimes to be endogenously determined by the data a time-varying transition probability Markov-switching VAR (TVTP MS-VAR) is employed. We identify two regimes; a non-crisis regime classified by low volatility and a crisis regime characterized by high volatility. The change in regime occurs in mid-2007, with the risky regime dominating thereafter. We find limited evidence of contagion during the crisis regime, and certainly not as widespread as in Longstaff (2010). This indicates that correctly dating the crisis is crucial to the analysis and suggests that risk may have filtered down through channels more closely related to the ABX before reaching the financial markets analysed.

Finally, Chapter 7 presents an overview of the main contributions and results of this dissertation along with proposing a number of future avenues of research that have arisen from this work.

Chapter 2

Credit Derivatives, Securitization and the U.S. Subprime Mortgage Crisis

2.1. Introduction

In mid-2007 the United States' financial system suffered its most severe crisis in almost a century, a crisis that led to a global recession worse than that experienced during the Great Depression of the 1930s (Eichengreen & O'Rourke, 2010). In the aftermath of the crisis it became clear that it had originated in the market for innovative financial products, namely structured finance products backed by U.S. subprime mortgages (Levitin et al., 2009). Such mortgages are granted to borrowers with poor or even no credit history and so are riskier than their prime counterparts. However, as illustrated in Figure 2.1, the market for securities backed by these mortgages was relatively small in 2007 compared to overall global securities markets and was, in fact, approximately one hundred times smaller than government and corporate markets (Dwyer & Tkac, 2009).

[**Insert Figure 2.1 about here**]

It is now apparent that the risk underlying these structured finance products was extremely underestimated and subsequently grossly mispriced (Orlowski, 2008). Following the crisis there have been calls for a complete review of the entire sector, particularly in the regulation of these securities and the incentives driving those trading them (Caprio et al., 2008). It is likely that the quality of the underlying asset will become crucial in future trading, as investors cautiously re-enter the market (Buiter, 2007).

This chapter describes how this tiny sector of the financial system contributed to one of the worst global financial crises experienced by examining the complex securities underlying this market. The remainder of this chapter is organised as follows. Section 2.2 describes credit derivatives in detail, while section 2.3 examines the process of securitization and the creation of asset-backed securities. It also gives details of traded credit indexes based on subprime mortgage-backed assets which are utilized in empirical applications throughout this thesis. Section 2.4 provides an overview of the U.S. crisis in relation to subprime mortgage-backed assets. A final section then concludes.

2.2. Credit Derivatives

In order to comprehend how structured finance products contributed to the collapse of the U.S. financial system it is important to first gain an understanding of how these structures operate at a fundamental level, and so this section describes the two central credit derivatives that formed the majority of these securities; credit default swaps (CDS) and collateralized debt obligations (CDOs). A simple derivative security may be classified as a bilateral financial contract in which pay-off is derived from an underlying asset or event. A credit derivative may be defined as a contract in which pay-off depends upon the creditworthiness of one or more companies or countries, referred to as reference entities. Default by a reference entity is known as a credit event. In recent years such securities have provided exciting advancements in derivatives markets, with gross notional principal outstanding for credit derivative contracts reaching almost \$60 trillion in 2007, an increase from below \$2 trillion in 2002 (Weistroffer et al., 2009).

Credit derivatives provide ways for financial institutions to diversify credit risk as they enable these organisations to reduce their credit exposure to borrowers.[1] These contracts allow institutions to actively manage and trade credit risks in a similar way to how they trade market risks (Hull & White, 2000) with banks the main buyers of this protection and insurance companies the main sellers (Bonfim, 2005). An important feature of credit derivatives is that neither the buyer nor the seller of the contract is required to possess the underlying asset, a characteristic that contributed to the markets rapid growth, but also to its opacity. Wagner (2007) argues that, although credit derivatives initially generated asset liquidity and led to a more stable banking system, this stability eventually weakened because banks began to engage in riskier behaviour. This moral hazard problem became a key contributing factor to the evolution of the crisis (Brunnermeier, 2008).

Credit derivatives may be classified as “single-name” or “multi-name”. The most popular single name credit derivative is known as a credit default swap (CDS).

2.2.1. Credit Default Swaps (CDS)

Credit default swaps (CDS) are a type of pure credit derivative and form the basis of the credit derivatives market (Hull, 2010).[2] These are privately negotiated contracts in which the buyer makes periodic payments to the seller so as to obtain a payment if a specified credit event occurs. The periodic payments are typically made in arrears every quarter, every half-year, or every year until the end of the life of the CDS or until a credit event occurs. In the event of a default the seller pays the amount insured to the buyer and receives the impaired asset. Consider, for example, two parties who

[1] Jarrow & Turnbull (1995) define credit risk as the risk that a loss will be experienced due to a default by the writer of the derivative security or by the asset underlying the security.

[2] Pure credit derivatives allow institutions to purchase protection on a single exposure.

enter into a five-year CDS on November 1, 2013, with a notional principal of $500 million in which the buyer is contracted to pay 70 basis points annually for insurance against default by the reference entity. Should the reference entity default, the seller of the CDS will be required to pay the face value of the bonds worth $500 million in return for the impaired asset. In the absence of a default the buyer receives no pay-off and pays $3,500,000 on November 1 for the next five years. Figure 2.2 illustrates this basic contract.

[**Insert Figure 2.2 about here**]

An institution's CDS spread is the amount paid per annum for insurance against default by the company, as a percentage of the notional principal. These spreads provide a measure of credit risk as a high cost of insurance would indicate the market's perception that the reference entity is more likely to default. CDS contracts enable financial institutions to actively control their risks, allowing credit risk to be transferred and diversified, thus reducing financial institutions credit exposure to particular reference entities (O'Kane, 2011).

However, credit default swaps operate in a, thus far, highly unregulated over-the-counter (OTC) market. This means that buyers of credit default swaps can essentially "naked short" companies' debts without restriction (Bender & Schneider, 2008). This lack of regulation in one of the world's largest and most active financial markets suggests that authorities either presumed that institutions would self-regulate or they simply did not expect a crash of major proportions. This market also suffers from an acute asymmetric information problem (Nicoló & Pelizzon, 2008) as some market participants undoubtedly have more information regarding particular companies than others, and sellers of insurance could potentially use this information to speculate.

In the wake of the crisis the Squam Lake Working Group (2009), among others, has suggested that there may be a role for a form of clearing house to attempt to regulate these derivatives and tackle the problem of asymmetric information.

Although the CDS market was, of course, hit by the crisis of 2007 it has, thus far, survived it remarkably well and financial institutions continue to use these instruments to manage their credit risks, with the notional amount outstanding at over $14 billion as of December 2012 (Bank for International Settlements Quarterly Review, June 2013).

2.2.2. Collateralized Debt Obligations (CDOs)

A typical multi-name credit derivative is the collateralized debt obligation (CDO). A CDO is a financial claim to cash flows produced by a portfolio of debt securities and so can facilitate the trade of the credit risk of entire portfolios. This removal of credit risk from the balance sheet of the originator is one motivation for CDO issuance. CDOs have been in existence since the late 1980s but were not widely traded until after 2000, with global CDO issuance increasing from just under $67 billion to over $520 billion between the years 2000 and 2006 (Securities Industry & Financial Markets Association). This growth is evident in Figure 2.3, as is the negative effect of the 2007-2009 crisis on issuance volumes.

[Insert Figure 2.3 about here]

In a CDO the assets are pooled together and then tranched according to the order in which investors will receive payment and the order in which they will be affected by defaults.[3] A basic CDO structure is illustrated in Figure 2.4.

[3] This is a form of asset securitization which is dealt with in more detail in the following section.

[Insert Figure 2.4 about here]

It is clear from Figure 2.4 that the senior tranche dominates, causing the structure to appear top heavy. This tranche offers the lowest return in the CDO and its investors receive payment first. In order for this tranche to be negatively affected sufficient defaults to wipe out both the mezzanine and equity tranches must take place, thus providing the senior tranche with a "virtual cushion" to absorb those losses. This cushion was one of the main reasons that this tranche usually received a AAA-rating, a process known as "credit enhancement" (Benmelech & Dlugosz, 2009). By this process financial protection is provided to cover losses on securitized assets, thus improving these asset's credit profiles and increasing their overall credit rating.

The equity tranche is located at the bottom of the CDO structure. As this is the first tranche to be affected by defaults it is the most risky in the CDO, therefore offering the highest return. Holders of this tranche are paid last. This risky security is usually unrated and highly illiquid, leading it to be labelled "toxic debt", and "toxic waste" at the height of the crisis. Due to its unpopularity with investors it was often held by the issuing financial institution, however in most cases it did not hold it directly on its books. Instead the bank held it in a separate legal entity, often owned by the parent bank itself, known as a special purpose vehicle (SPV).[4] An SPV is a bankruptcy-remote company that financial institutions utilize to raise cheaper financing by issuing short-term debt.[5] It may also be used to help remove credit risk from a balance sheet by moving risky loans to the SPV. SPVs are usually funded using short-term borrowing by issuing asset-backed commercial paper (ABCP) which is continuously rolled over

[4] Also known as a special purpose entity (SPE), a structured investment vehicle (SIV) or simply a conduit.

[5] Bankruptcy-remote means that it should not be affected by bankruptcy of the originating bank.

to invest in long-term assets that are less liquid but pay higher returns.[6] The ABCP market was considered to be the most liquid part of the market in the years preceding the crisis. The maturity mismatch resulting from the combination of long-term lending and short-term borrowing was a major contributing factor to the liquidity crisis that followed the subprime crisis as institutions became unable to roll over their debt. These SPVs also helped to create what became known as a "shadow banking system" (Adrian et al., 2010).[7]

As well as a way of dealing with a lack of demand for these assets another motivation for the SPV to hold the equity tranche would be to inspire investor confidence in these assets. However, appreciating property prices caused by the housing bubble in the run-up to the crisis meant that these institutions had little qualms about holding such a risky security. For many the reasoning at the time was that if defaults did occur they would gain possession of an apparently continuously appreciating asset. It appears that the possibility of mass defaults was not seriously considered by many of these banks in the period preceding the crisis.

The mezzanine tranche lies between the senior and equity tranches, and is usually rated between AA and BBB. As the senior tranche was most popular with investors during the period preceding the crisis and the equity tranche was usually held by the SPV, there existed no natural buyer for the mezzanine tranche, causing it to become the most difficult to sell. To increase the appeal of the mezzanine tranche to investors the creators of these structures began to repackage the mezzanine tranches of several deals together to create new CDOs. These CDOs were then rated as separate entities,

[6]ABCP typically has a maturity of between 90 and 180 days.

[7]The Financial Crisis Inquiry Commission of 2010 defines shadow banking as, *"...bank-like activities that are conducted outside the traditional commercial banking system, many of which are unregulated or lightly regulated."*

with the senior tranches of the new securities usually receiving AAA ratings, as discussed by Watterson (2005). These CDOs backed by portfolios of other CDOs became known as CDO squareds, and the growth in popularity and subsequent increase in demand for these securities then led to the creation of CDO cubeds, which are CDOs backed by a portfolio of CDO squareds. Unsurprisingly this form of financial alchemy resulted in these securities becoming increasingly complex and interconnected. This meant that a default in one, instead of remaining isolated to that security, negatively affected others, leading to mass losses. The AAA rating that approximately 80% of the structure subsequently received led investors to believe that a AAA-rated CDO security was equivalent to a similarly rated corporate bond and, as these new structured finance products were yielding higher returns, demand for them sky-rocketed (Wojtowicz, 2011).

Scheicher (2008) estimates the relationship between CDO tranche premia and market-based measures of credit, liquidity and interest rate risk. It is found that the observed increase in tranche premia can be largely attributed to a declining risk appetite and increased concerns about liquidity. The CDO market was severely damaged during the crisis and there followed a "flight to quality", during which investors turned to safer assets such as government bonds (Longstaff, 2010).

2.3. Securitization and Asset-Backed Securities (ABS)

As the credit derivative market began to experience rapid growth so did the process of credit securitization (Henke et al., 1998) and by the early 2000s the two had become interlinked, together laying the foundations for the crisis of 2007. Securitization is a process by which institutions reconstruct assets that they hold into tradable securities which are then sold on to investors. The transformation of an illiquid asset into a tradable security has the effect of making it more liquid than the loan underlying it. The security usually takes on the tranche structure described in section 2.2.

Mortgages are among the most commonly securitized assets (Minton et al., 1997) and were historically considered to be part of the relatively stable housing market, a trend observed up until approximately 2000, illustrated by Figure 2.5.

[**Insert Figure 2.5 about here**]

Securitization of mortgages began in the 1970s, with Ginnie Mae, Fannie Mae and Freddie Mac the main market participants (Barth et al., 2008).[8] However, it was not until the 2000s, with the surge in popularity of innovative financial products, such as CDOs, that the market for these securities really took off. This led to what became known as the "originate and distribute" model, in which financial institutions issue loans which are then pooled together and tranched in order to resell to investors. This is opposed to the conventional "originate and hold" strategy that banks traditionally followed, in which financial institutions issue loans and then simply maintain them on their balance sheet. These two models are illustrated by Figure 2.6.

[**Insert Figure 2.6 about here**]

It is clear from Figure 2.6 that this new system brought more players into this market while also causing it to become highly interconnected. Instead of the originating institution bearing all of the credit risk from loans, as in the "originate and hold" model,

[8] The Government National Mortgage Association, the Federal National Mortgage Association and the Federal Home Loan Mortgage Corporation, respectively.

the risk is distributed among several investors and the SPV in the "originate and distribute" model, meaning that all are negatively affected by defaults. These linkages led to the entire financial system suffering when mass mortgage defaults did occur. The securitization process enabled investors to select securities according to their risk preferences and was initially hailed by many as a valuable instrument for reducing risk. In 1999 the then chairman of the Federal Reserve, Alan Greenspan, stated in a speech to the Futures Industry Association that these derivatives were, *"an important vehicle for unbundling risks"*. However, as the demand for these securitized loans rapidly increased in the mid-2000s, the "originate and distribute" model ultimately contributed to a severe reduction in lending standards (Purnanandam, 2011; Keys et al., 2010; and Kiff & Mills, 2007). To meet this demand for mortgages to securitize, many lenders relaxed their screening methods and granted loans to borrowers who were ultimately unable to repay them. Wall Street banks began demanding more and more loans from mortgage lenders and suddenly people who previously had not qualified for a mortgage had their choice of loans from brokers. Brunnermeier (2008) suggests that it was this "originate and distribute" model, along with the maturity mismatch of financial institutions loans and borrowings, that led to the recent financial crisis.

2.3.1. The ABX.HE Indexes

2.3.1.1 Overview of Indexes

The exceptional growth of the subprime mortgage-backed securities sector during the early 2000s led to the creation of the ABX.HE indexes, standardized indexes that provided credibility, transparency and liquidity to this relatively new and innovative structured finance market.[9] Produced by the Markit Group, trading on the ABX was launched on January 19, 2006, to enthusiastic investors. Indeed, volume on the first trading day was reported to be approximately $5 billion, although this decreased in subsequent trading days (Whetten, 2006). The name ABX.HE denotes "Asset-backed securities index-home equity" and it represents a standardized basket of home equity asset-backed reference obligations, basically a basket of synthetic CDOs underlying subprime mortgages.[10] The indexes track twenty equally weighted, static U.S. portfolios of credit default swaps backed by subprime mortgages. Each vintage takes on a CDO structure, covering specifically rated reference obligations (AAA, AA, A, BBB, and BBB-).[11] Ratings are the lower of those issued by Moody's and Standard and Poor's (S&P's). AAA-rated ABX securities thus reference a specific AAA-rated class from each of the twenty portfolios of subprime mortgage-backed credit default swaps, while AA-rated ABX securities reference AA-rated class from the pool and so on down to BBB-. However, considering that there are approximately fifteen tranches in each mortgage-backed security and the indexes only take into account five of these the ABX cannot be seen as a perfect representation of the market. Nonetheless it is the closest proxy available (Finger, 2007).

2.3.1.2 Overview of Index Construction

Each ABX vintage is based on twenty subprime mortgage-backed securities issued over the previous six-month period and vintages are renewed or "rolled" every six months.

[9]Throughout this thesis the ABX.HE indexes may be referred to as the "ABX", the "ABX indexes" or "ABX vintages". Note that the terminology "ABX index" and "ABX vintage" is used interchangeably. "ABX asset", "ABX ratings class" and "ABX rating tranche" refers to the assets comprising each index/vintage

[10]In a synthetic CDO the underlying credit exposures are obtained using a credit default swap. In comparison to cash CDOs, which have a referenced portfolio comprised of cash assets such as loans, the reference portfolio of a synthetic CDO is made up of credit default swaps.

[11]See section 2.2.

Only four vintages have been issued, with the fifth subject to several postponements and unlikely to go ahead.

Each vintage is a synthetic CDO in which the ratings do not differentiate borrowers according to how risky they are. Instead they simply distinguish the order in which investors bear losses and receive payments. The misconception that a AAA-rated ABX asset was equal to that of a corporate bond led many mandate-driven bodies, such as pension funds and universities, to heavily invest in these securities.

2.3.1.3 ABX Construction Process

In order to construct each ABX vintage the Markit group submit a list to each licensed dealer of two deals from the largest 25 subprime home equity issuers. To be included in the ABX indexes each residential mortgage-backed security (RMBS) must meet stringent requirements, such as deal size must be at least $500 million, the weighted average Fair Isaac Corporation (FICO) score of the creditors backing the securities issued in the RMBS transaction may not be greater than 660 and at least four of the required tranches must be registered pursuant to the U.S. Securities Act of 1933.[12] Deals must pay on the 25th of each month, at least 90% of the deals' assets must be 1st lien mortgages, referenced tranches must bear interest at a floating rate benchmark of one-month London Interbank Offered Rate (LIBOR) and, at issuance, each deal must have tranches of the required ratings with a weighted average life greater than four years, except the AAA which must have an average life of longer than five years.

On the following day, each dealer submits to Markit a ranking of their preference of

[12]In the U.S. an individual's credit risk is commonly measured by a FICO score. These scores range from 300 to 850 and are based on analysis of the individual's credit history. A mortgage issued to a borrower with a FICO score of 620 or less is classified as a subprime mortgage.

deal for each issuer. From these submissions Markit creates a master list of 20 deals conditional on no more than four deals with loans from the same originator and no more than six deals with the same master servicer. These conditions are an attempt to ensure diversification within each vintage.

At least four days prior to the creation of each new vintage Markit notifies dealers of its composition, then publishes this information.

Each vintage contains this same list of reference obligations until all reference obligations have been fully paid off or have matured. On the day before each vintage creation date, each market maker submits to Markit a fixed rate for it, based on their calculations. The average of these spreads rounded up to the nearest basis point then serves as the fixed rate.

2.3.1.4 ABX Pricing Mechanics

As the crisis of 2007 unfolded it became clear that the ABX indexes had been grossly mispriced. Fender & Scheicher (2008) propose one way to calculate ABX prices as:

$$p = 100 + c\sum_{l=1}^{n} z_i s_i t_i f_i - (1-\delta)\sum_{l=1}^{n} z_i(s_i - 1 - s_i)f_i, \tag{2.1}$$

in which p=index price, c=coupon payment, z=risk-free discount factor, s=probability of no default, t=time period, δ = recovery rate (i.e. the price of the bond immediately after default as a percentage of its face value) and$f$=bond factor measuring prepayments on ABX bonds. This may be written in simplified terms as:

$$Price = 100 + PV(Coupons) - PV(Writedowns), \tag{2.2}$$

in which 100 is the par value of the index. The present value of the coupons is fixed as a percentage of notional over the life of the vintage on it's initiation. It is paid by the protection buyer to the protection seller for insurance should a credit event occur. The present value of write-downs or losses is variable and is paid from the protection seller to the buyer in the case of a credit event. Equations (2.1) and (2.2) highlight that it is vital that the value of the coupons be high enough to cover potential losses. However, as it transpired, they were not and when defaults began accumulating write-downs rapidly increased. Protection sellers simply could not afford to cover losses.

An alternative way to consider ABX prices is presented below:

$$ArtificalCDOprice = HypotheticalRiskFreeBondPrice - ObservedCDSPremium \tag{2.3}$$

A CDO, like a bond, has an observable price. However, a CDS has only an observable premium. Because each ABX vintage is a synthetic CDO created using a CDS we must create an artificial CDO price by subtracting the observed CDS premium from a hypothetical risk-free bond price.

In order to further understand ABX pricing mechanics consider the following example. Suppose on March 6th 2006 we wish to purchase $10 million of the ABX 06-1 AAA-rated tranche. The coupon, fixed at initiation, is 20 basis points and the ABX price on that day is 98. The price we pay is as follows:

$$Price = [Notional(Coupon + (100 - price)Factor)], \tag{2.4}$$

=[10,000,000 x (.0020 + (100% - 98%))x 1] = 220,000, As equation 2.4 indicates, we pay pay the notional amount of $10 million multiplied by the coupon plus a once-off payment of the difference between par and the quoted ABX price. This is then multiplied by the factor, which is a measure of current notional outstanding. A factor of one indicates that no deals in the vintage have defaulted.

Now, suppose that one of the twenty deals in the vintage completely defaults. In this case we receive:

$$10{,}000{,}000 \text{ (Change in Factor)} = 10{,}000{,}000 \text{ x } 0.05 = 500{,}000$$

and we now pay:

$$[10{,}000{,}000 \ (.0020 \text{ x } 0.95)] = 19{,}000$$

which is the notional amount multiplied by the product of the coupon and the new factor.[13]

Figure 2.7 plots ABX raw prices for each vintage from its issuance date until December 31, 2009.[14]

[**Insert Figure 2.7 about here**]

There is clearly a steep decline in prices in all four vintages over the sample period. As the subprime deals underlying the ABX 06-1 vintage were issued in the second half of 2005 the assets underlying this vintage would be of considerably better quality than those included in later issuances. It is clear that all assets in this vintage traded at or near par for all of 2006 before declining rapidly during 2007, a trend evident in the

[13] Note that the difference between par and the quoted ABX price is only paid when the contract is entered into.

[14] Note that as each vintage was issued six months subsequent to the previous issuance the data are unbalanced.

other three vintages. However, the AAA-rated asset in the ABX 06-1 vintage does not reach the lows of later issued AAA assets and it is clear that the two later issued vintages were hardest hit by the crisis. Sabry & Okongwu (2009) calculate that a $100 investment in the ABX 07-1 vintage BBB asset in January 2007 was worth just $5 by September 2008. Trading in the ABX came to almost a complete halt following the subprime crisis of mid-2007. It did resume following the shock as investors tentatively re-entered the market but it is highly unlikely that trading volumes will ever reach the highs experienced in the months leading up to the crisis. However, the Markit Group Ltd. did report a 39% increase in the price of AAA-rated assets within the ABX 06-1 vintage in 2012 and a report issued in November 2012 by Goldman Sachs recommended its clients invest in the ABX indexes, reflecting improvements in the housing market.

2.4. The 2007 U.S. Subprime Mortgage Crisis

As mentioned earlier, in the aftermath of the 2007 crisis it transpired that it had originated in the subprime mortgage-backed securities market. However, before looking into this market in more detail it is useful to investigate the environment that facilitated its development. In 1998 the Federal Reserve Bank of New York organised a $3.6 billion bailout of Long-Term Capital Management (LTCM), hailing the return of the "too big to fail" doctrine (Dowd, 1999). The early 2000s witnessed the burst of the dotcom bubble, sending financial markets into chaos. This situation was compounded by the U.S. terrorist attacks of 2001, prompting central banks worldwide to implement strategies aimed at creating liquidity and stimulating the global economy. Many adopted accommodative interest rate policies, particularly the Federal Reserve. In fact the Federal Funds Rate, the rate at which depository institutions lend to each other overnight, was decreased eleven times between January and December 2001 (Federal Reserve Bank of New York) creating readily available credit in markets. In order to take advantage of this investors began to undertake riskier investments with the aim of obtaining higher absolute returns. This encouraged lenders to take on greater risks also, thus leading to an unprecedented increase in the issuance of risky subprime mortgages. Originations of such mortgages reached record levels of $665 billion in 2005, as illustrated in Figure 2.8, and this contributed to the inflation of a housing bubble.

[**Insert Figure 2.8 about here**]

Along with taking on riskier loans there was also an increase in institutions undertaking the process of securitizing debt.[15] This practice was not new, however previously securitized debt was usually held on balance sheet and used as collateral to fund borrowing. Now institutions began securitizing different types of underlying assets, such as credit card debt, and moving loans off balance sheet. During the mid-2000s subprime mortgages were extensively securitized, with approximately 80% of subprime loans repackaged as mortgage-backed securities (MBS) between 2001 and 2005 (Barth et al., 2008).

Such mortgages relied upon the constant appreciation of house prices in order for the system to function as many borrowers were refinancing in order to keep afloat (Gorton, 2009). The decrease in house prices in 2007 therefore burst the bubble, leading to numerous foreclosures and defaults and, consequently, the financial crisis (Shiller, 2008).

As mentioned earlier a subprime mortgage may be defined as a mortgage granted to a

[15] See section 2.3.

borrower with poor credit history or, in some cases, even no credit history (Hull, 2010). As illustrated in Figure 2.8 between 2003 and 2006 issuance of these subprime mortgages increased rapidly and home ownership grew for the first time in nearly twenty years (U.S. Census Bureau). In fact at the height of the mortgage selling frenzy brokers were issuing what became known as "NINJA" mortgages, in which the borrower had "no income, no job or assets". It also became common to accept little or no down payment, with many lenders offering as high as 150% mortgages. It is now clear that this new model created incentive problems for those issuing mortgages as ultimately they did not bear the credit risk, motivated to simply originate as many as possible. It led to an acute asymmetric information problem as institutions purchasing packages of these mortgages had little knowledge of their risk, the reality being that the banks knew much more about the holders of the mortgages than those buying the loans did. These problems compounded one other and these products became extremely opaque and obscure. It is estimated that up to 80% of loans issued to subprime borrowers during this time were "hybrid" loans (U.S. Structured Finance Newsletter, October 2005) such as adjustable rate mortgages (ARMs) with low "teaser" rates that enticed people to take these loans out. As soon as the teaser rate expired, interest rates increased; often at an alarming pace. In most instances institutions were required to hold the loans for a minimum of three months to prove that the mortgage payer was credit worthy, so these ARMs could have led those purchasing the mortgages to believe that they were much less risky than in reality. As the institutions were then selling the loans on and therefore transferring the credit risk to those purchasing them the creditworthiness of the borrower was of little concern to them. As mentioned earlier many borrowers were refinancing and living off the equity on their houses, a system that functioned well as long as house prices continued to appreciate. Indeed during this boom period the U.S. saw an increase in the practice of what became known as "flipping houses", in which people bought houses, kept them a short period of time until the price appreciated and then sold them on, making a profit. However, by the third quarter of 2006 this system came under pressure as house price appreciation began to slow (Federal Housing Finance Agency). New buyers found it increasingly difficult to obtain mortgages and house prices began to decline. This led to those already with mortgages unable to refinance, which then led to mortgage delinquencies by both prime and subprime borrowers. These delinquencies mounted and it soon became clear that a major mispricing of the risk of these mortgage-backed structured securities had occurred. Many of the AAA-rated subprime mortgage-backed securities were downgraded to junk overnight (Connor et al., 2010). These announcements caused widespread panic for institutions holding these products. In August 2007 France's largest investment bank, BNP Paribas, announced that it had temporarily suspended valuation of three funds invested in U.S. asset-backed securities and that it had also frozen redemptions until liquidity returned to the market. This shook up the entire system, causing the crisis to spread to interbank lending and leading to a worldwide liquidity crisis in the fall of 2008, initiated by the collapse of Wall Street giant Lehman Brothers on September 15th. Brunnermeier (2008) offers a detailed explanation of the crisis by examining what led to its occurrence, describing four main economic devices that may have enabled the mortgage crisis to evolve into the far-reaching liquidity crisis. The instruments presented are the balance sheet effects of borrowers, the disintegration of liquidity, and the influence of bank runs and network effects on financial institutions' wealth. When considering balance sheet effects it is important to bear in mind capital requirements as once these requirements are met the average return earned on loans may be less appealing than that on other assets. Therefore loans can behave in an almost illiquid manner and maintaining them on the balance sheet may seem disadvantageous.

The most widely used international regulations for capital requirements are outlined in the Basel Accords. The first Basel Accord of 1988 required banks to hold 8% of regulatory capital, a requirement reduced under Basel II in 2007. These capital requirements are intended to provide banks with suitable motivation to properly control their risk. However, in the early 2000s, banks discovered that they themselves could reduce these requirements by pooling their loans into SPVs, as discussed in section 2.2.2. The repositioning of a group of the banks loans into such an off-balance sheet vehicle and the subsequent credit line that the bank then awarded it in order to promote liquidity and encourage confidence ensured that these institutions could decrease their required regulatory capital without altering their risk. This is known as “regulatory arbitrage”. However, even though it did not appear on the banks balance sheet the majority of credit risk remained with the banks as they still held the loans, albeit in a conduit. This left them exposed to substantial funding liquidity risk. As banks were relying more and more upon liquidity in order to sustain this new system they simply could not afford it to suddenly evaporate.

The credit line, known as “liquidity backstop”, also ensured that the pool received a AAA-rating, achieved through the diversification of non-systematic risk. It is important to note that this rating was awarded to the CDO tranche, not the individual assets comprising that tranche. As discussed in section 2.2.2 this became known as “credit enhancement”, the phenomenon that each asset individually may be of low quality but once pooled together a large proportion of the security receives a AAA-rating. Pension funds, universities and police retirement funds tend to have ratings mandates by which they may only invest in AAA-rated securities. Therefore these investors were now able to enter the market. Also, as Basel II was based on asset ratings this strategy succeeded in substantially reducing capital charges.

It is noteworthy that credit rating agencies received higher fees for structured finance products and also made their software available to those that they were rating. Also, the statistical models used to rate these securities were based on historical house prices over a relatively short period of time, ten years in some cases, and the assumption that they could only appreciate. They therefore provided overly confident estimates regarding the risk of default. In hindsight it appears that the models used to rate these assets were extremely complex and unrealistic. The Financial Crisis Inquiry Commission report into credit ratings in 2010 quoted former Moody's Managing Director Jerome Fons as describing methods of credit analysis as *"beyond the grasp of many investors"*.

The third mechanism Brunnermeier (2008) outlines is the effects of runs on financial institutions. He concludes that the first-mover advantage may make these institutions subject to such runs. The final mechanism described is network effects, whereby institutions lend and borrow simultaneously, a practice undertaken by many institutions preceding the crisis. Here, network and gridlock risk are encountered as each institution cannot pay its debts because other market participants are not paying theirs.

2.5. Conclusions

The majority of literature available on the subject suggests that distorted incentives and moral hazard problems had a large role to play in the recent financial crisis. It also claims that what occurred was a standard, albeit large in magnitude, crisis following the burst of a housing bubble. Demyanyk & Hemert (2011) examine subprime mortgage loan quality and calculate that it was in decline for six years in the run up to the crisis. Interestingly they also claim that those repackaging the loans had some knowledge of this. They conclude that the crisis followed a typical boom-bust cycle and could have been avoided had the high house prices caused by the bubble not served to mask the underlying problems.

Purnanandam (2011) concludes that a distortion in screening incentives and excessive risk-taking led to the crisis, while Mah-Hui (2008) compares this crisis to past crises and concludes that they are similar in nature. Financial innovation, and particularly its contribution to systemic risk, is cited as a contributing factor. Whalen (2008) cites failure of regulatory bodies and government policies as the largest contribution to the crisis while Murphy (2008) places the blame with the unrealistic assumptions adapted by the financial models employed at the time.

The Financial Crisis Inquiry Commission, employed by the United States government with the aim of investigating what caused the crisis, concluded in its final report in January 2011 that *"the crisis was avoidable and was caused by: Widespread failures in financial regulation, including the Federal Reserves' failure to stem the tide of toxic mortgages; Dramatic breakdowns in corporate governance including too many financial firms acting recklessly and taking on too much risk; An explosive mix of excessive borrowing and risk by households and Wall Street that put the financial system on a collision course with crisis; Key policy makers ill prepared for the crisis, lacking a full understanding of the financial system they oversaw; and systemic breaches in accountability and ethics at all levels"*.

It is clear that a severe deterioration in incentives, failures in regulatory organisations and complex, innovative structured finance products led to the financial crisis of 2007. It was preceded by a period of uncertainty and turbulence, fuelled by accommodative interest rates and policies intended to restore the economy and brought to unparalleled heights by corruptive behaviour, irrational risk taking and a lack of regulation.

Figure 2.1: Relative Size of Global Financial Markets (2007 Figures).
Figure compiled using data sourced from the Bank of England Stability Report, 2007.

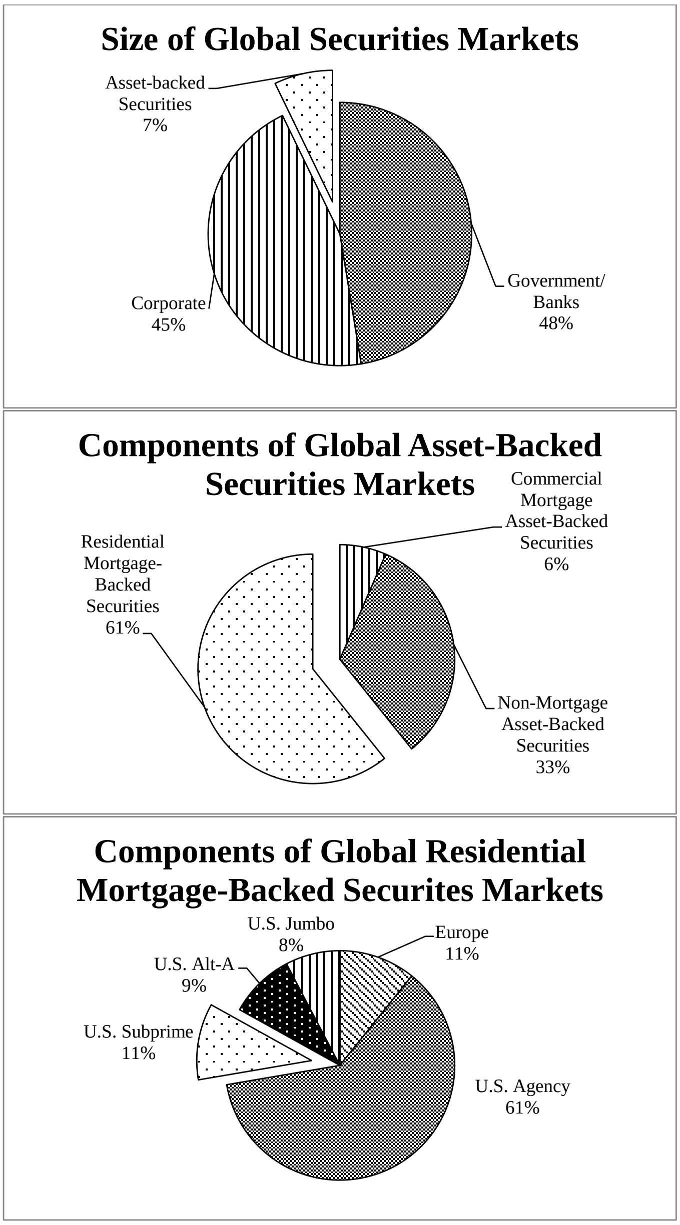


Figure 2.2: Credit Default Swap (CDS).

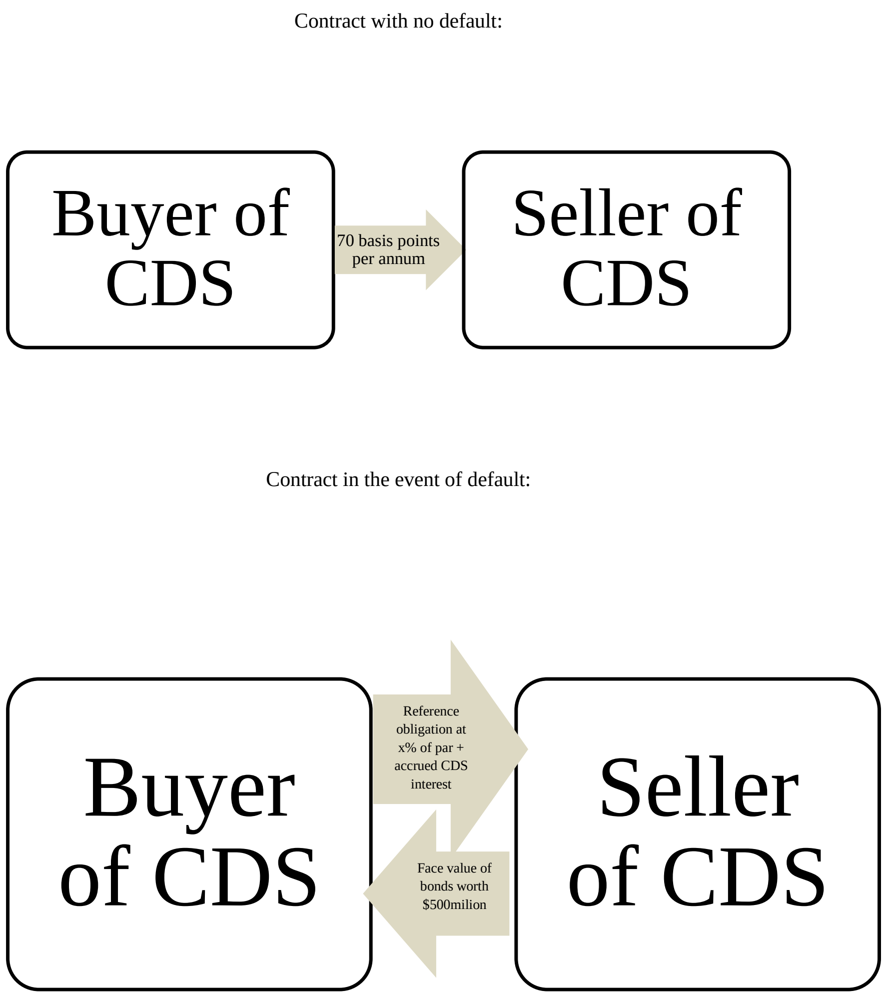


Figure 2.3: Global CDO Issuance 2000-2013.
Figures in USD billions. Figure compiled using data sourced from the Securities Industry and Financial Markets Association (SIFMA).

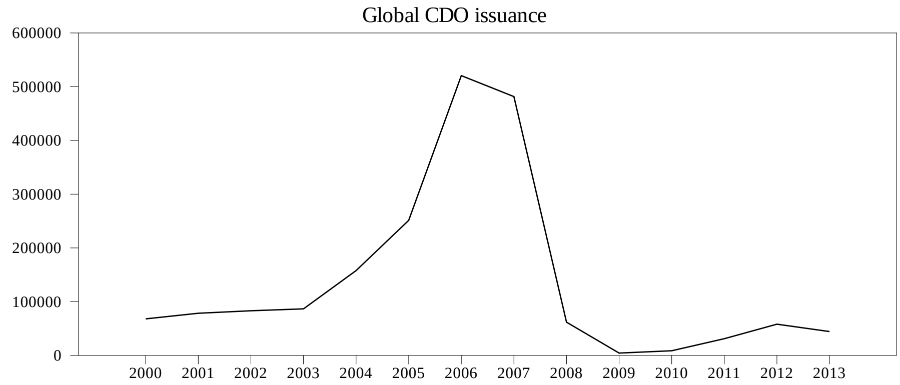


Figure 2.4: Basic CDO Tranche Structure.

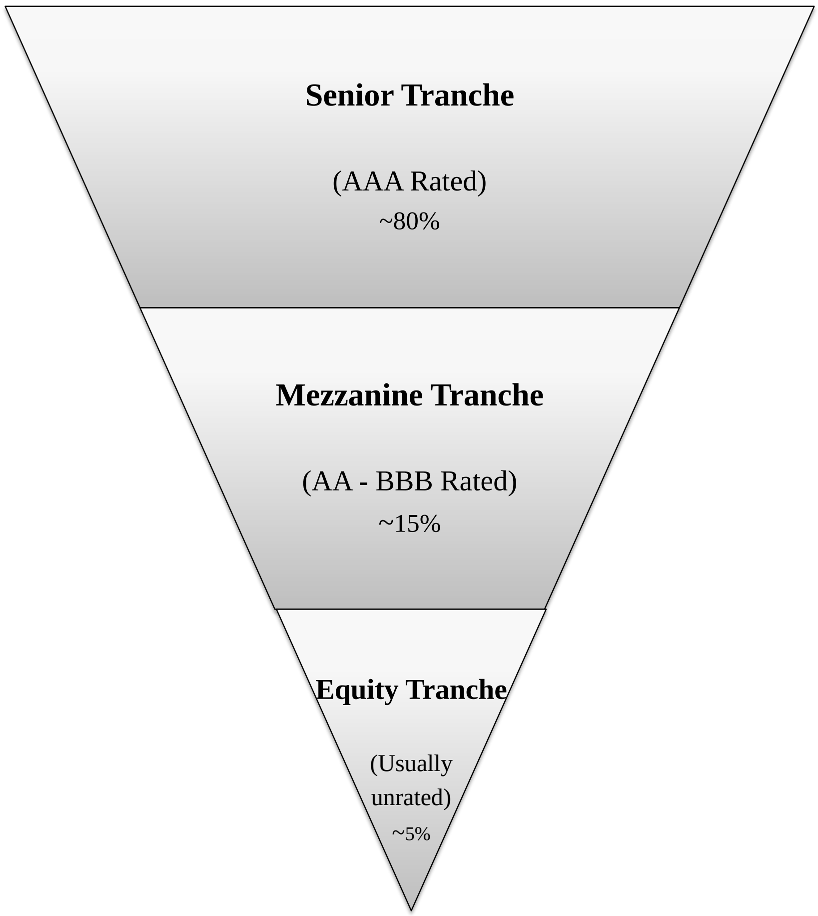


Figure 2.5: United States' House Prices.
Inflation adjusted U.S. house prices. Figure compiled using data sourced from the Federal Housing Finance Agency.

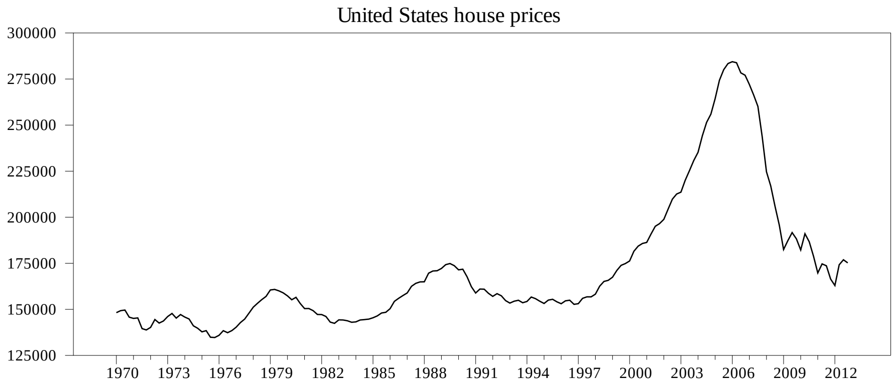


Figure 2.6: Originate and Hold Model vs Originate and Distribute Model.
Panel A illustrates the Originate and Hold model; Panel B illustrates the Originate and Distribute model.

A: Originate and Hold Model

B: Originate and Distribute Model

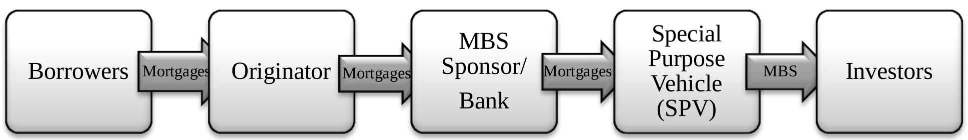


Figure 2.7: ABX Indexes Raw Prices.

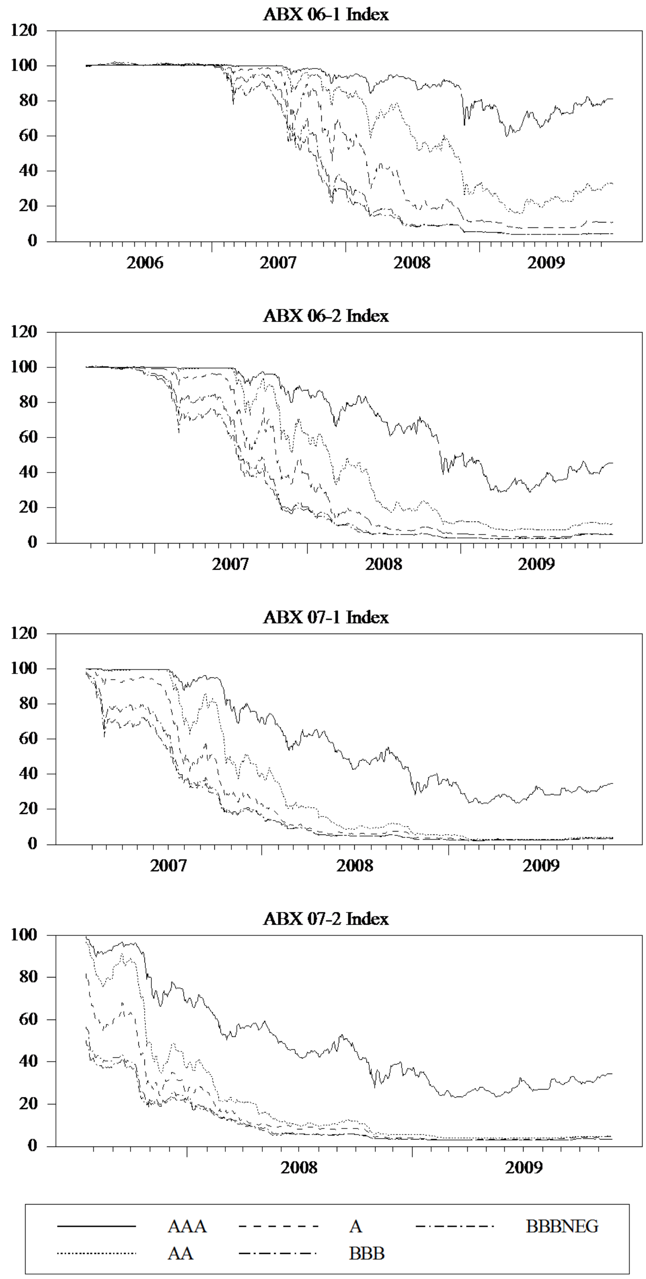
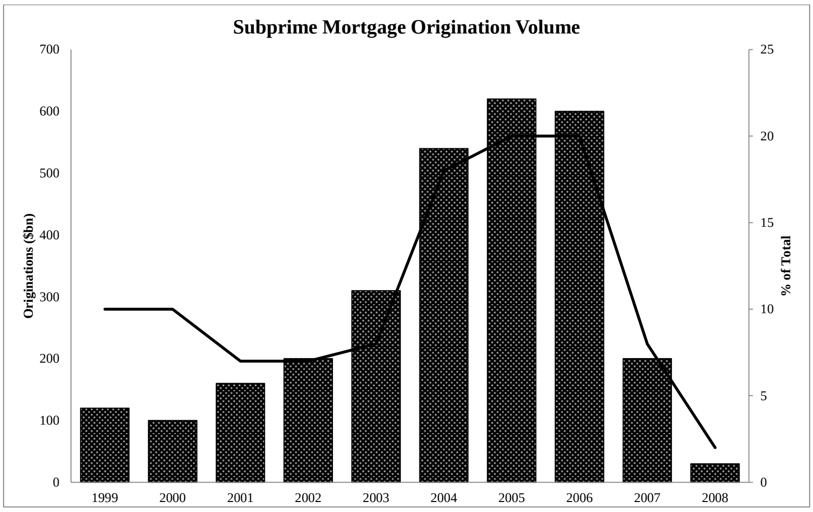


Figure 2.8: Subprime Mortgage Origination Volume.
The left hand side vertical axis illustrates subprime mortgage originations in USD billions; the right hand side vertical axis illustrates these subprime mortgage originations as a percentage of total originations. Figure compiled using data sourced from Inside Mortgage Finance.



Chapter 3

Identifying Risk Factors Underlying the U.S. Subprime Mortgage-Backed Securities Market

3.1. Introduction

The years preceding the 2007 financial crisis saw the United States enter an environment of unprecedented growth and prosperity, the "great moderation" as it became known, a period in which the financial system experienced some of its largest gains in history (International Swaps & Derivatives Association) and many Americans achieved their dream of home ownership. Ownership grew most rapidly amongst previously disadvantaged groups such as African Americans and Hispanics, as illustrated in Figure 3.1.

[**Insert Figure 3.1 about here**]

This period followed the bursting of the dotcom bubble and the terrorist attacks of 2001, creating a need to encourage growth and confidence back into the system. In an attempt to do so the U.S. government introduced many accommodative interest rate policies which led to an abundant availability of credit and a boom in the housing market, causing home ownership to increase for the first time in two decades. Home ownership increased from 66.8% in 1999 to 69% by the end of 2005, leading many to conclude that the market was experiencing a speculative bubble (Goodman & Thibodeau, 2008). As with any bubble, a bust was inevitable. And the bust that did occur led to one of the worst recessionary periods experienced in almost a century (Sapir, 2009). In the aftermath it became clear that the root of the problem lay in the market for innovative subprime mortgage-backed securities, a relatively new and small market (Dodd, 2007). It also became clear that these complex securities had been misunderstood and vastly mispriced by the majority of those trading them, a serious error that led to chaos in the U.S. financial system and sent financial markets worldwide into turmoil (Sanders, 2008).[1] Therefore this chapter aims to explore the risk underlying these complex securities, in order to gain an insight into how a crisis that began in the relatively small subprime mortgage-backed securities sector did not remain isolated to the real estate market, instead spreading rapidly across global financial markets, affecting investor confidence, general market liquidity and real economies worldwide.

In order to examine this market this chapter focuses on the ABX.HE indexes, the only available proxy for the U.S. subprime mortgage-backed securities market.[2] These indexes became a key barometer of subprime mortgage market conditions for institutions and investors in the run-up to the crisis. In order to analyse the ABX OLS regression analysis is initially performed to establish correlation between the vintages and several macroeconomic variables that proxy for risk factors, namely house prices, market volatility, liquidity and counterparty risk. The results suggest that mainly U.S. house prices are significantly related to ABX returns over the sample period. Next, principal component analysis (PCA) is performed on the four ABX vintages, in order to reduce the dimensionality of such a noisy data set. The results suggest that the importance of the principal components driving variation in ABX returns differed across vintages, indicating that these were heterogeneous assets with different risk profiles. These principal components are used in subsequent OLS regression analysis in

[1]These products are examined in detail in Chapter 2.
[2]See Chapter 2.

place of ABX returns to establish correlation between these and the above-mentioned macroeconomic variables. The results indicate that these principal components are significantly related not just to house prices, but general market volatility, liquidity and counterparty risk. A rolling regression analysis is then performed to observe coefficient behaviour over the crisis period. The results illustrate the development of the crisis from a real estate problem to a much broader global crisis. The analysis is also performed according to asset rating, the results of which suggest that the rating of the asset had an effect on the principal components underlying it more so than the vintage that it was issued in and that lower-rated assets were susceptible to more risk factors than higher-rated tranches.

The chapter is organised as follows. Section 3.2 provides a timeline of the crisis, outlining important events, and section 3.3 discusses related literature. Section 3.4 then describes the data used in the analyses with section 3.5 reviewing the methodology and discussing the results. Section 3.6 discusses the analysis performed according to ratings tranche and section 3.7 then concludes.

3.2. Timeline of the 2007 United States financial crisis

As discussed in Chapter 2 the foundations of this crisis were set in the early 2000s in response to a slump in the markets caused by the bursting of the dotcom bubble and the terrorist attacks of September 11th, 2001 (Kregal, 2008). Low interest rates fuelled a housing bubble and investors began to realise large gains from mortgage-backed securities. However, by 2006 some players in the market were beginning to question the quality of the assets underlying these securities. By December 2006 mortgage delinquencies and foreclosures were increasing (Sapir, 2009) and Goldman Sachs altered the firms' position on the mortgage market from positive to negative, although this information was not released publicly (New York Times, December 2009). On February 27th 2007 Freddie Mac declared its intention to cease the purchase of the most risky subprime mortgages and mortgage linked securities. On April 2nd a leading subprime lender, New Century Financial Corporation, filed for Chapter 11 bankruptcy protection and by June mass downgrades of subprime mortgage-backed securities had begun. June 1st saw S&P's and Moody's rating agencies downgrade more than one hundred bonds backed by these securities and on July 11th S&P's placed 612 such products on credit watch.[3] By the end of the year interbank liquidity was rapidly drying up; with the LIBOR-OIS spread, widely seen as a measure of strength in the banking system, reaching an all time high of 108 basis points on December 6th (Federal Reserve Bank of St. Louis). This contrasts with a spread of just 10 points before the full force of the subprime crisis hit markets in August 2007. Such a high spread is a clear indicator of uncertainty and mistrust within the banking system as institutions became less willing to lend to each other due to concerns about increasing counterparty risk.

Numerous measures were implemented in an attempt to rescue the failing banking system, such as several cuts of the Federal Funds Rate and the introduction of the Economic Stimulus Act of 2008 in February. Nonetheless, things continued to deteriorate and in early March the 85-year old Bear Stearns collapsed and was subsequently acquired by JP Morgan for $2 a share (Wall Street Journal, March 2008). One year prior to this Bear Stearns had been trading at almost $160 per share and just five days before the takeover the share price stood at over $68, as illustrated in Figure 3.2.

[3] Credit watch indicates that, following a review of the company or security in question, that company's or security's credit rating may be changed.

[Insert Figure 3.2 about here]

In autumn 2008 the crisis reached a critical turning point. On the 15th of September the fourth largest investment bank in the United States, Lehman Brothers, filed for bankruptcy following drastic losses as the market rapidly lost confidence in the 158-year old Wall Street giant. The bank had failed to receive a bailout from the government or a buyout from another institution and became the largest bankruptcy in U.S. history. The fact that one of the largest investment banks in the United States was allowed to fail shook up Wall Street, causing even more panic and loss of confidence in the financial system. Also, Lehman Brothers was one of the largest players in the ABCP market, meaning that their demise curtailed liquidity in the system. On the same day, Bank of America announced its intention to purchase one of the "Big Five" U.S. investment banks, Merrill Lynch, for $50 billion.[4] The following day the Federal Reserve Bank of New York was authorized to lend up to $85 billion to the American International Group (AIG), a company that mainly traded credit default swaps. In early October the Emergency Economic Stabilization Act of 2008 was passed by congress, establishing the $700 billion Troubled Asset Relief Program (TARP), which was announced publicly on October 14th. In early January 2009 the Federal Reserve Bank of New York had begun to purchase fixed-rate mortgage-backed securities guaranteed by Fannie Mae, Freddie Mac and Ginnie Mae and the U.S. Treasury Department purchased a total of $4.8 billion in preferred stock from forty three U.S. banks under the Capital Purchase Program. The remainder of the year saw the introduction of several strategies aimed at saving the banking system and promoting economic recovery, such

[4]Prior to the crisis the top five investment banks were 1: Goldman Sachs, 2: Morgan Stanley, 3: Merrill Lynch, 4: Lehman Brothers and 5: Bear Stearns. In 2010 the Financial Times reported that the "Big Five" were now: 1: JP Morgan, 2: Goldman Sachs, 3: Bank of America Merrill Lynch, 4: Morgan Stanley and 5: Citi.

as the “American Recovery and Reinvestment Act of 2009”, which included a variety of spending measures and tax cuts, and “The Homeowner Affordability and Stability Plan”. In July Congress announced the members of the Financial Crisis Inquiry Commission, an organisation established to investigate the causes of the crisis. Despite such measures, the crisis continued to worsen and spread to other countries and markets. From the events outlined above it is clear why the period of September 2008 is viewed by many as the climax of the crisis (Ivashina & Scharfstein, 2010). Table 3.1 outlines important market events that occurred during that month.

[**Insert Table 3.1 about here**]

3.3. Related Literature

As yet the literature examining the ABX indexes remains relatively sparse. Fender & Scheicher (2008) perform principal component analysis (PCA) and regression analysis on the first two vintages issued in order to ascertain the relevance of several pricing factors and how they may have changed over time. They find that for the higher-rated assets risk appetite and liquidity risk become more significant while becoming less important for the lower quality ratings. They suggest that these factors had a large role to play in the deterioration of ABX prices as it was established that there were considerable unobserved factors driving subprime mortgage risk. However, it should be noted that the data analysed in Fender & Scheicher (2008) end in mid-2008, before the onset of the credit crunch. Dungey et al. (2013) analyse three ratings classes over three vintages of the ABX by using a latent factor model in order to uncover the factors behind the decline in the mortgage-backed securities market. They find that common and liquidity effects have an increasing influence on the performance of the ABX. They also find that the influence of vintage factors varies significantly over the period analysed, ultimately declining in significance as they become swamped by common risk factors. Gorton (2009) analyses the relationship between repurchase agreements and the ABX and finds the two to be intricately related to one another. Mizrach (2011) analyses jump and co-jump frequency in the ABX and CME housing futures and finds that jumps appear prior to 2007, and that these are more pronounced in the housing futures markets. It is also found that almost 85% of jumps can be explained by news and housing futures. Though closely related to both Fender & Scheicher (2008) and Dungey et al. (2013), our analysis covers a longer sample than the former and extends the asset coverage of the latter. Hence, this study can provide additional insights into the behaviour of the subprime mortgage-backed securities market.

3.4. Preliminary Analysis

This chapter uses daily price data from four ABX vintages as described in Chapter 2. Returns have been generated from daily index prices using log differences and the sample ranges from January 19, 2006, until December 31, 2009. Table 3.2 reports summary statistics for the daily log returns of each vintage.

[**Insert Table 3.2 about here**]

It is clear from Table 3.2 that normality is rejected in all cases, indicated by high excess kurtosis. Unsurprisingly, we observe negative means throughout, along with negative skewness. The minimum values exceed the corresponding maximum values in most cases, indicating that the losses experienced outweighed the gains realised. The lower-rated assets and the later vintages display higher standard deviations than the higher-rated assets and earlier issuances, suggesting these assets were riskier. Raw correlation coefficients between the assets in each vintage are presented in Table 3.3.

[**Insert Table 3.3 about here**]

The degree of correlation among almost all assets fell with each subsequent vintage issuance, suggesting that the strength of these relationships diminished with time. However, the correlation coefficients vary among vintages, indicating that these were not homogeneous assets and should be treated as separate distinct securities. Figures 3.3 - 3.6 plot the time series of ABX returns for each vintage over the sample period.

[**Insert Figures 3.3 - 3.6 about here**]

The effect of the crisis on ABX returns is evident. Returns in all ratings tranches are relatively stable until mid-2007, after which they all became extremely volatile as the subprime crisis hit markets.

A number of macroeconomic variables are included as explanatory variables in the analysis. Each of these variables provides a proxy for a different risk factor that could affect the ABX and has been used in related literature to date, such as Fender & Scheicher (2008), Murphy & Murphy (2010) and Dungey et al. (2013). Log returns of the Dow Jones Equity Real Estate Investment Trust Index (REIT) provide a proxy for U.S. house prices, seen by many as the driver of the financial crisis. In the absence of a high frequency property price index we follow Dungey et al. (2013) in using this as an indicator of the U.S. real estate sector. The Chicago Board Options Exchange Market

Volatility Index (VIX) provides a measure of volatility. The LIBOR-OIS spread, considered to be a measure of strength of the banking system, is included as a proxy for credit risk, as described by Mc Andrews et al. (2008). The OIS-Tbill spread provides a proxy for liquidity risk, as explained by Eichengreen et al. (2012). First differences of the VIX, LIBOR-OIS spread and OIS-Tbill spread are also analysed, in order to examine if changes in these variables could influence ABX returns. Summary statistics for the macroeconomic variables are reported in Table 3.4.

[**Insert Table 3.4 about here**]

There is a large difference in magnitude between the house price proxy and the other variables due to the fact that the REIT is reported in log returns while the other variables are reported in levels. Relatively high standard deviations indicate the high volatility of these variables during the sample period, which is reinforced by the large difference between the minimum and the maximum values. High levels of excess kurtosis indicate that normality is rejected in all cases. Unsurprisingly, the house price proxy log returns experience both a negative mean and negative skewness while the other risk proxies are all mean positive. The differenced VIX and LIBOR-OIS spread both experience negative means, indicating that changes in the VIX were negative over the whole sample period and the LIBOR-OIS spread was narrowing. Changes in the OIS-Tbill spread are mean positive, suggesting that this spread was widening, perhaps as investors turned to more safer assets.

All macroeconomic variables are graphed for the full sample period in Figures 3.7 and 3.8, which clearly show the effect of the crisis on these variables. For example, we observe jumps in the VIX and the two spreads in mid-2008, indicating an increase in volatility, credit risk and liquidity risk at this time.

[Insert Figures 3.7 - 3.8 about here]

3.5. OLS Regression Analysis 1

The two regression equations employed are:

$$ABX_{i,t} = \alpha + \beta_1 REIT_t + \beta_2 VIX_t + \beta_3 LIBOROIS_t + \beta_4 OISTBILL_t + \epsilon_t, \quad (3.1)$$

and

$$ABX_{i,t} = \alpha + \gamma_1 REIT_t + \gamma_2 \delta VIX_t + \gamma_3 \delta LIBOROIS_t + \gamma_4 \delta OISTBILL_t + \epsilon_t, \quad (3.2)$$

in which $ABX_{i,t}$ denotes ABX vintage daily log returns, $REIT$ denotes U.S. real estate investment trust daily log returns, VIX denotes daily VIX volatility index levels, $LIBOROIS$ denotes daily LIBOR-OIS spread levels and $OISTBILL$ denotes daily OIS-Tbill spread level. δ denotes that the indicated variable is differenced. Table 3.5 reports OLS results for equation 3.1. T-statistics are reported in parentheses.

[Insert Table 3.5 about here]

The house price proxy is significant in almost all cases, suggesting that this variable was a major driver of variation in ABX returns. In the ABX 07-1 and 07-2 vintages only house prices are significant, although this is mostly in the higher-rated assets. This is probably due to the fact that the two lower-rated assets in the two riskiest vintages would have experienced very low trading volumes once the crisis hit and so may have been subject to “stale” prices. It is also possible that variation in these lower-rated assets may have been driven by something other than house prices. The results suggest that the higher-rated tranches in the later vintages are most sensitive to house price changes over the sample period, which is not surprising as the mortgages underlying these vintages were issued during the crisis period and so would have been of lower quality than those included in the earlier vintages and among the first to enter negative equity.

Table 3.6 reports OLS results for equation 3.2. T-statistics are reported in parentheses.

[**Insert Table 3.6 about here**]

Again, house prices are found to be the main driver of ABX returns, with other variables largely irrelevant. However, as discussed above, related literature, such as Dungey et al. (2013) and Fender & Scheicher (2008), suggest that other factors had an influence on ABX returns as the crisis evolved. Therefore, in order to delve further into these securities, and specifically into the risk underlying them, principal component analysis (PCA) is performed in an attempt to extract the common factors underlying the variation in the ABX data.

3.6. Principal Component Analysis (PCA)

OLS regression analysis on noisy data such as ABX returns may lead to imprecise results, as the analysis could potentially pick up noise in the data (Granger & Newbold, 1974). It is therefore useful to reduce the dimensionality of the data, while still maintaining as much of the variation as possible. Principal component analysis (PCA) achieves this without losing any information from the data. Similar to factor analysis, PCA is designed to uncover a small number of factors that describe most of the variation in a large number of correlated variables. It focuses on variances and reduces data dimensionality by performing a covariance analysis between factors. It is a useful descriptive instrument used to reveal unidentified trends in data sets consisting of a large number of interrelated variables, while retaining much of the variation present. This is accomplished by transforming the principal components, which are uncorrelated and ordered so that the first few contain most of the variation present, to a new set of variables.[5] Mathematically PCA is an orthogonal linear transformation, meaning that the principal components obtained are unrelated to each other. The data are transformed to a new coordinate system such that the greatest variance lies on the first coordinate, and so is the first principal component. The second largest variance lies on the second coordinate and is the second principal component, and so on.

The results of PCA are usually considered in terms of component scores, which calculate how much of the variance of each data point is associated with a particular principal component, and factor loadings, which indicate the extent to which the principal components are related to the original variables. PCA is a statistical procedure that provides an alternative way to visualize the data and so it does not provide information regarding what the principal components actually are or what they are a result of, just the extent to which they contribute to the variation in the data.

[5]PCA consists of the following steps: 1.Organise the data set. 2.Calculate the empirical mean. 3.Calculate deviations from the mean. 4.Calculate the covariance matrix. 5.Find the eigenvectors and eigenvalues of the covariance matrix. 6.Rearrange the eigenvectors and eigenvalues. 7.Choose components and form a feature vector. 8.Derive the new data set (Smith, 2002).

3.6.1. PCA Results According to Vintage

Figure 3.9 plots the time series of principal components for each vintage over the entire sample period.

[**Insert Figure 3.9 about here**]

Between 2006 and 2007 there is almost no movement as this was a relatively tranquil period for these assets during which the realisation of price risk was low. Moving into the crisis period from mid-2007 onwards they fluctuate widely, as the subprime crisis and subsequent credit crunch hit. In order to analyse the individual components the average relative importance of each component in each vintage is calculated and graphed in Figure 3.10.

[**Insert Figure 3.10 about here**]

The first principal component, the main contributing factor to the variation in the data, accounts for over 60% of variation in ABX returns in each vintage. PCA is successful in reducing the dimensionality of the problem with the first three components capturing approximately 90% of all variation in each vintage. However, the first principal component actually falls in importance between the first and last vintage. This suggests that the components driving the variation in the ABX data differed across vintages which could be due to the fact that each subsequent vintage was issued in an increasingly volatile time period, during which these assets were exposed to more risk factors, such as the liquidity crisis in September 2008. It also highlights the fact that these vintages were unique and not simply an extension of the previous issuance, indicating that these assets were heterogeneous and should be treated as separate entities, a finding consistent with Dungey et al. (2013). The chief driving factor is not as important in the later vintages and the four remaining components contribute more to the variation in the data in subsequent issuances. Possible reasons for this could be that during this time investors were rapidly losing confidence in these assets upon realising that they were more risky than they had first appeared and were beginning to reassess them. What followed was a period of accelerated "selling off" of these products during which investors not only exited the lower-rated tranches but the entire mortgage-backed securities market. Retrenchment and re-structuring of the banking sector during this volatile period could account for the increasing importance of the other principal components here. During this time it is possible that house prices were not as important for ABX returns as liquidity and counterparty risk as institutions were rapidly losing trust in each other and were becoming increasingly unwilling to engage in interbank lending. As stated, the first three components capture most of the commonality and therefore the remainder of the analysis focuses on these three only as the main driving factors in this market.

As mentioned earlier because each new vintage was issued six months following the previous vintage each data set analysed has a different starting point. In order to ascertain if this had any effect on the behaviour of the principal components, the analysis is also carried out with all the data starting at the same point, the beginning of the ABX 07-2 vintage in July 2007, and the results do not change considerably. This suggests that this phase, during the crisis, contributed most variation to these assets.

3.7. Regression Analysis 2

OLS regression analysis is re-performed using the three main principal components obtained from each vintage as dependent variables instead of the noisy, higher dimensional ABX returns in an attempt to obtain clearer results relative to the initial regression analysis. The two regression equations employed are:

$$PC_{i,t} = \alpha + \beta_1 REIT_t + \beta_2 VIX_t + \beta_3 LIBOROIS_t + \beta_4 OISTBILL_t + \epsilon_t, \quad (3.3)$$

and

$$PC_{i,t} = \alpha + \gamma_1 REIT_t + \gamma_2 \delta VIX_t + \gamma_3 \delta LIBOROIS_t + \gamma_4 \delta OISTBILL_t + \epsilon_t, \quad (3.4)$$

in which $PC_{i,t}$ denotes the principal component. Tables 3.7 and 3.8 report OLS results for equations 3.3 and 3.4. T-statistics are reported in parentheses.

[Insert Tables 3.7 - 3.8 about here]

House prices are still significant throughout, again indicating that they play a role in explaining the variation in the data. However, we now observe more factors coming into play relative to the initial regressions performed, such as volatility, liquidity and credit risk, suggesting that these factors also have an effect on ABX returns over the sample period. This corresponds with investor concerns during the crisis switching from the downturn in the housing market to the credit worthiness of financial institutions and the declining availability of credit in the banking sector. We again see differences between vintages. For example, the strongest relationships between the principal components and the macroeconomic variables occur in the first two vintages, indicating that these earlier issuances reacted to the risk factors examined more so than the later issued vintages. This is interesting as these two vintages, and particularly the January 2006 issuance, would have been perceived to be the safest as they were issued before the crisis hit. However, it is possible that the realisation by investors that this was not the case led to an increased sensitivity to risk. These vintages issued at the tail end of the boom period would have been in higher demand than those issued later during the crisis phase and so when the crisis hit it is possible that there were in fact more investors in these two vintages than the subsequent issuances, who were then panicking and attempting to offload these assets. This again reinforces the idea that there were marked differences between vintages and that these assets should be treated as heterogeneous. Also, it again suggests that the risk factors driving ABX returns varied as time went on, changing from predominantly house prices to liquidity, volatility and credit risk. This change highlights the crisis' move from the housing market into the broader credit sector. Fender & Scheicher (2008) also find support for the relevance of risk appetite and liquidity risk for the ABX vintages.

However, from the results it is clear that, although there is some significance, the coefficients themselves are quite small and the R^2s range only from 0.008 to 0.04 and so explain very little of the variation in the data. One possible reason for the small coefficient estimates could be that the independent variables are highly correlated with each other. In order to investigate this further correlation coefficients between the independent variables are reported in Table 3.9.

[**Insert Table 3.9 about here**]

The VIX is highly correlated with both the LIBOR-OIS spread and the U.S. real estate price index. This relatively high correlation may have impacted the previous results reported. Another potential problem OLS regression analysis can suffer from is that, by imposing a constant coefficient, it does not capture the time varying property of the variables (Wooldridge, 2003). One possible method to overcome this problem is to employ univariate rolling regression analysis.

3.8. Rolling Regression Analysis

Rolling regression analysis calculates parameter estimates over a rolling or "moving" window of a fixed size throughout the sample. Due to the short data range in our analysis a relatively small window of fifty observations is chosen.[6]

3.8.1. Rolling Regression Results

We perform the rolling regression analysis using the first three principal components of all vintages as dependent variables. However, to conserve space we only present graphical results for the first vintage in Figures 3.11 - 3.16. Since the graphs for later vintages are similar, we refer to any differences without including the additional nine graphs.[7]

[Insert Figure 3.11 - 3.16 about here.]

The solid lines in the graphs presented in Figures 3.11 - 3.16 are point estimates; the dashed lines are confidence bands. From these results it is clear that all risk proxies exhibit considerable time variation once the crisis period kicks in. In the time period

[6] In order to confirm the robustness of the results larger window sizes, such as 100, are also employed and the results do not change qualitatively.

[7] All results are available on request.

before it, between 2006 and 2007, we see no variation due to the lack of variability in the ABX returns and principal components during the relatively tranquil period. The proxies for house prices and volatility begin to exert an influence in 2007, corresponding with the beginning of the fall of the housing market (Di Martino & Duca, 2007). We also see that the proxies for liquidity and counterparty risk come into play much later, around mid-2008. The liquidity crisis occurred between September 15th and October 12th 2008 (Sapir, 2009), with events such as the acquisition of Merrill Lynch by Bank of America (September 14th), the fall of Lehman Brothers (September 15th) and the $85 billion bailout of AIG (September 16th), which can be viewed as critical points in the crisis. From this we can conclude that the risk factors underlying the subprime mortgage market changed over time as the crisis wore on, and these changes correspond to the evolution of the crisis from a purely real estate problem to a liquidity problem for the entire banking system. We see a shift from house prices and volatility having an influence to liquidity and counterparty risk becoming important. This suggests that concerns about liquidity and the strength of the banking system became at least as important as concerns regarding the housing market, as Brunnermeier (2008) also argues.

3.9. Analysis According to Ratings Tranche

As we have seen there are considerable differences in the behaviour of the assets analysed across vintages. The next step is to ascertain if there also exists differences in the assets across ratings classes. Therefore the analysis is performed according to the five ratings tranches in an effort to examine if the different ratings classes exhibit various sensitivities to different risk factors.[8] Table 3.10 reports summary statistics according to ratings class.

[Insert Table 3.10 about here]

Table 3.10 indicates that these assets are highly volatile during the sample period, with normality rejected in all cases. Mean returns are negative for every asset, and in almost every instance are monotonically related to vintage, again indicating the higher volatility of later issuances. Table 3.11 reports correlation coefficients between each ratings tranche and equivalent assets in the other vintages.

[Insert Table 3.11 about here]

There is a weakening degree of co-movement as asset rating declines. This indicates that the higher-rated assets had more in common than the lower tranches during the sample period. The relative importance of the principal components obtained for each ratings class is presented in Figure 3.17.

[Insert Figure 3.17 about here]

Differences between the assets of each vintage are evident from Figure 3.17. We see that the AAA-rated tranche contains most commonality of all ratings classes with really only one factor contributing to the variation of this asset. As this was perceived to be the safest asset on sale it may be the case that there is less noise trading in this rating class. While it is clear that there is much commonality in the AAA tranche the BBB- tranche shows the most variation between principal components, implying that it was

[8] Note that in this analysis all data have the same starting point, July 19, 2007, the date that the final vintage was issued.

driven by risk factors that were not impacting the higher tranches. Fender & Scheicher (2008) also find differences between the lower- and higher-ratings, particularly that the higher-rated assets react more to the declining financial market environment while the lower tranches are more sensitive to fundamental factors.

These results imply that the risk factors underlying the ratings classes of ABX assets changed more dramatically than those underlying the vintages, suggesting that the rating of the asset has a large bearing on how it behaves in crisis times. As it is clear that the AAA-rated tranche holds the most commonality OLS regression and rolling regression analyses are performed on this asset over the four vintages to ascertain whether the macroeconomic variables employed had an effect on them. Table 3.12 reports OLS results for equations 3.3 and 3.4. T-statistics are reported in parentheses.

[Insert Table 3.12 about here]

The only significant effect comes from the house price proxy for the first principal component, reinforcing the theory that real estate market movements were the driving factor in this tranche over the sample period and indicating that, for the highest-rated assets on sale, only house prices have a significant influence. Again, however, the coefficients and R^2's are very small and so rolling regression analysis is employed. As AAA-rated assets comprised most of the CDO structure and the main principal component accounts for 90% of the variation only results for the principal component underlying this asset are reported as this indicates that this was the dominant force driving returns. Figures 3.18 and 3.19 plot the rolling regression analysis results and display a similar pattern to previous results.

[Insert Figure 3.18 - 3.19 about here]

Firstly, all coefficients display time variation. Secondly, we see that house prices and volatility have an effect throughout the time period and the other proxies have very little influence until late 2008, with the onset of the liquidity crisis. This suggests that, for these highest-rated assets, house prices are significant in their returns throughout but, as investor concerns regarding liquidity and counterparty risk increase, these other factors begin to have a significant effect on ABX products.

3.10. Conclusions

This chapter examines the U.S. subprime mortgage-backed securities market by using the closest proxy available for it, the ABX indexes. OLS regression analysis, principal component analysis (PCA) and rolling regression analysis are performed on the ABX vintages in an attempt to examine this complex market, and to better understand the risk underlying it. The overall results suggest that different risk factors came into play at different times over the course of the crisis of 2007-2009. Analysis according to vintage suggests that proxies for U.S. house prices and volatility are more significant during 2007, corresponding with the beginning of the deflation of the housing bubble. As the crisis wore on, proxies for liquidity and credit risk change from exhibiting very little significance to playing a more important role, consistent with the onset of the liquidity crisis in September 2008. Analysis according to ratings class suggests marked differences between ratings classes, with the highest-rated tranche containing most commonality, a finding in line with Dungey et al. (2013). Rolling regression analysis shows house prices and volatility have a consistent influence throughout the period analysed, with liquidity and counterparty risk again coming into play during the 2008 credit crisis. Brunnermeier (2008) also highlights the growing importance of liquidity, credit risk and counterparty risk during the crisis.

These results indicate that concerns about house prices and volatility became compounded by concerns about liquidity and credit risk, a trend consistent with the evolution of the crisis. They also suggest that the lower-rated tranches were exposed to more risk factors than the higher-rated assets during the sample period and that tranche effects supercede vintage effects. Fender & Scheicher (2008) highlight differences between ABX ratings classes, particularly that the higher ratings were impacted by different risk factors than the lower ratings. To further analyse the ABX, and specifically differences that may exist between tranches, Chapter 4 analyses contagion within the indexes themselves.

Figure 3.1: U.S. Home Ownership Rates According to Race and Ethnicity of Householder.
The home ownership rate is the percentage of home owning households among all households in the given demographic group. Figure compiled using data sourced from the Information Please Database, Pearson Education Inc.

Figure 3.2: Bear Stearns Stock Price March 2007 - March 2008.
Figure compiled using data sourced from the Bloomberg system.

Figure 3.3: ABX 06-1 Vintage Daily Log Returns.

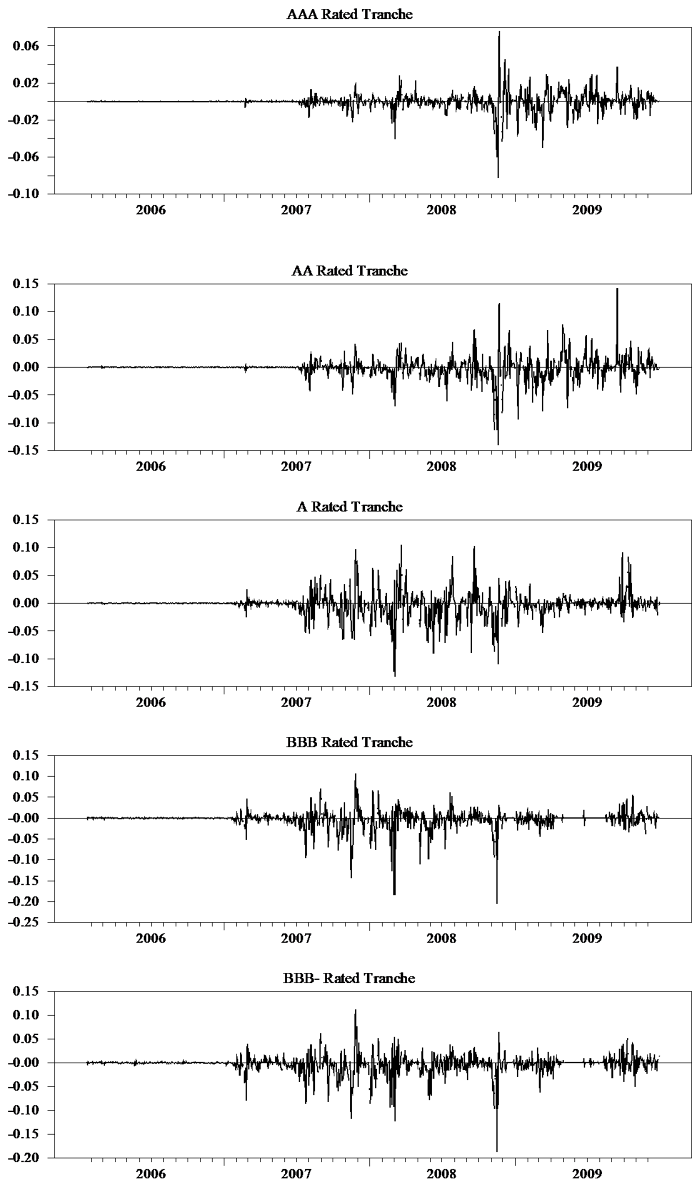


Figure 3.4: ABX 06-2 Vintage Daily Log Returns.

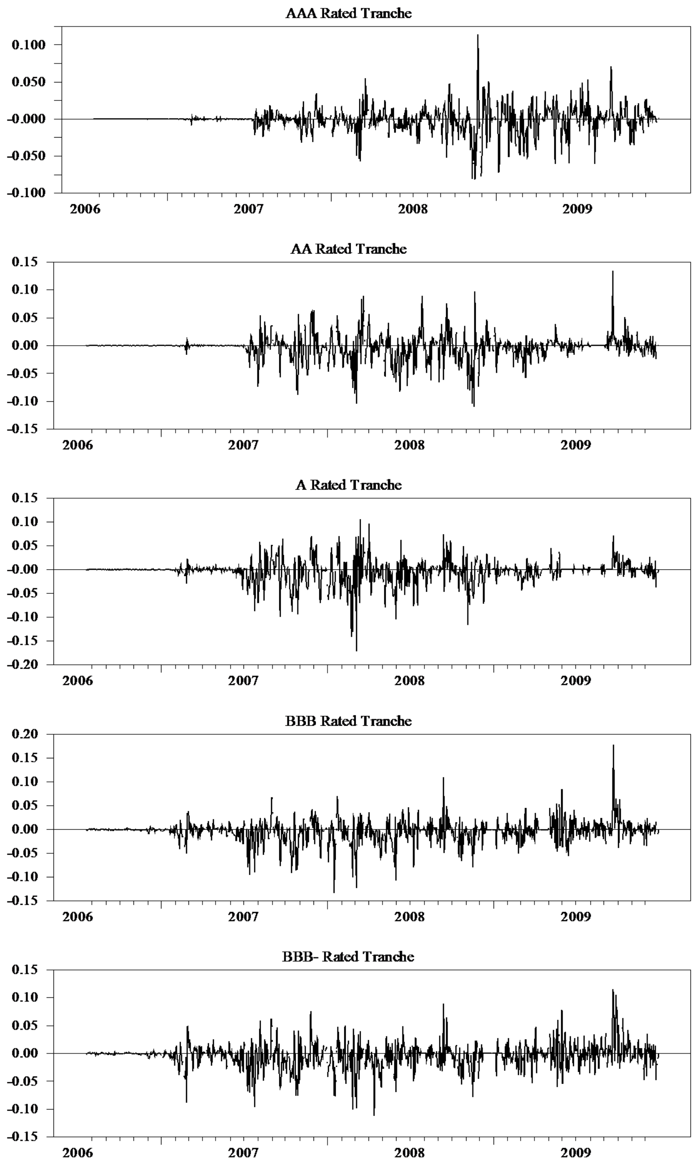


Figure 3.5: ABX 07-1 Vintage Daily Log Returns.

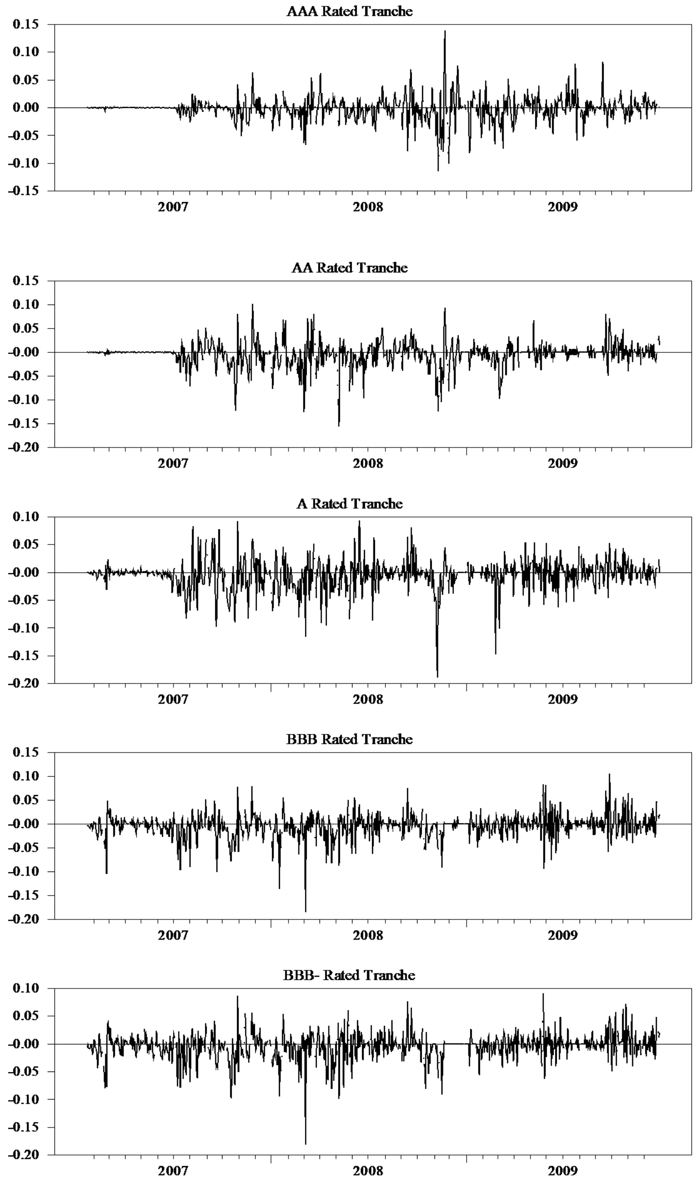


Figure 3.6: ABX 07-2 Vintage Daily Log Returns.

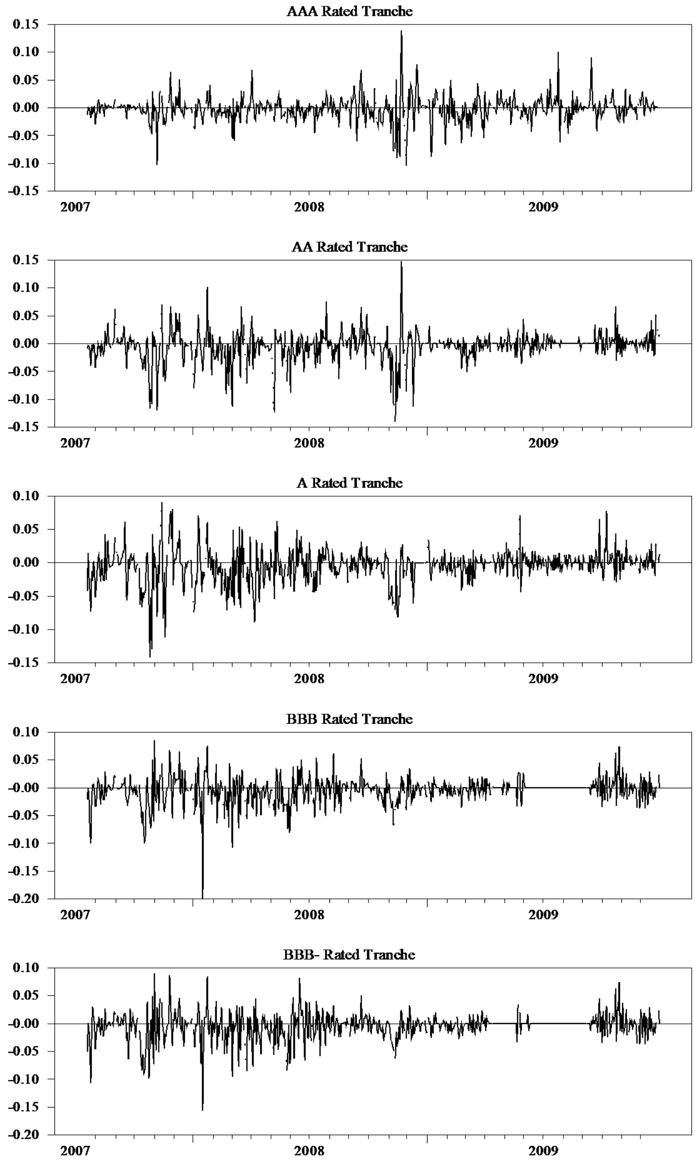


FIGURE 3.7: Macroeconomic Variables 1.

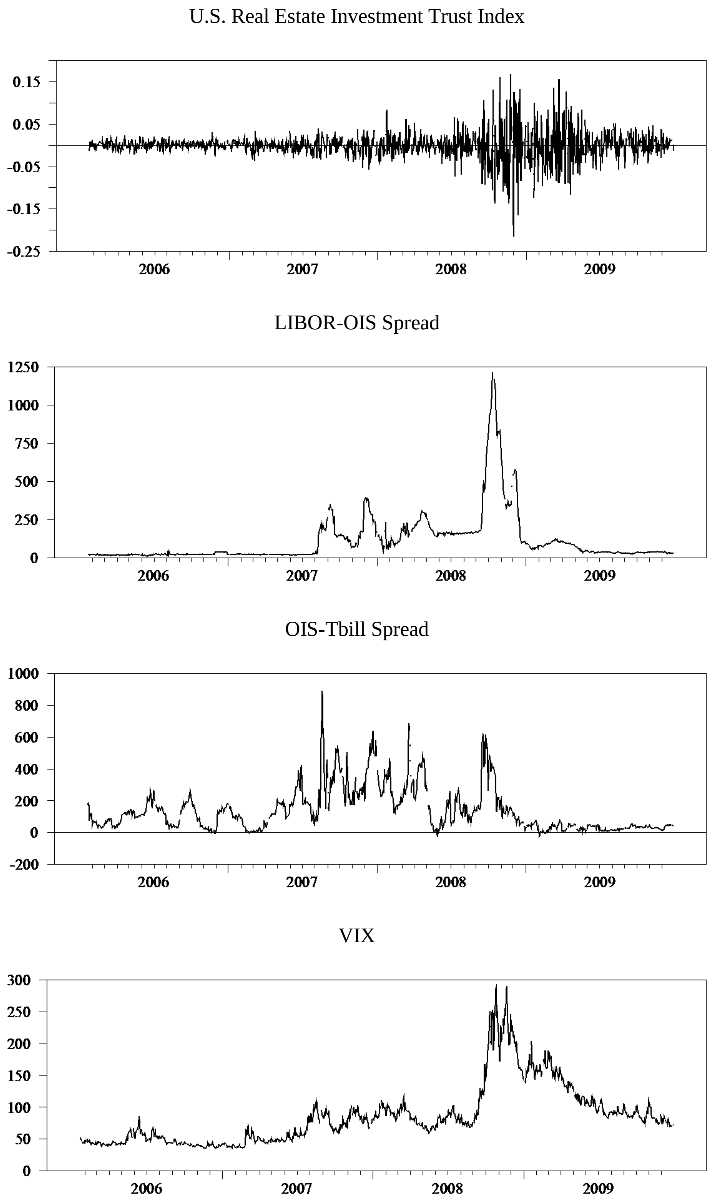


FIGURE 3.8: Macroeconomic Variables 2.

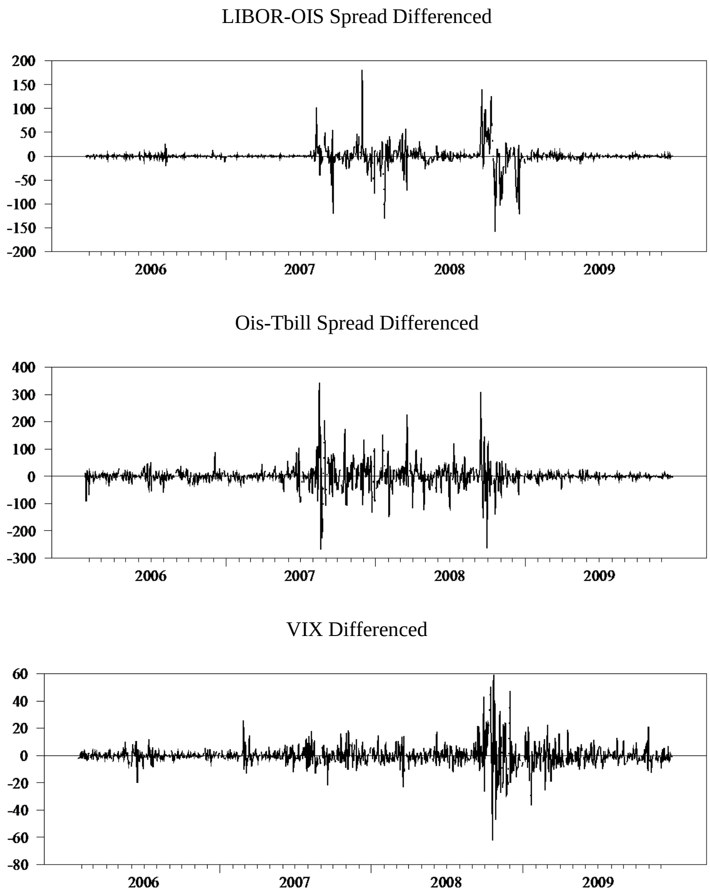


FIGURE 3.9: Principal Components Time Series.

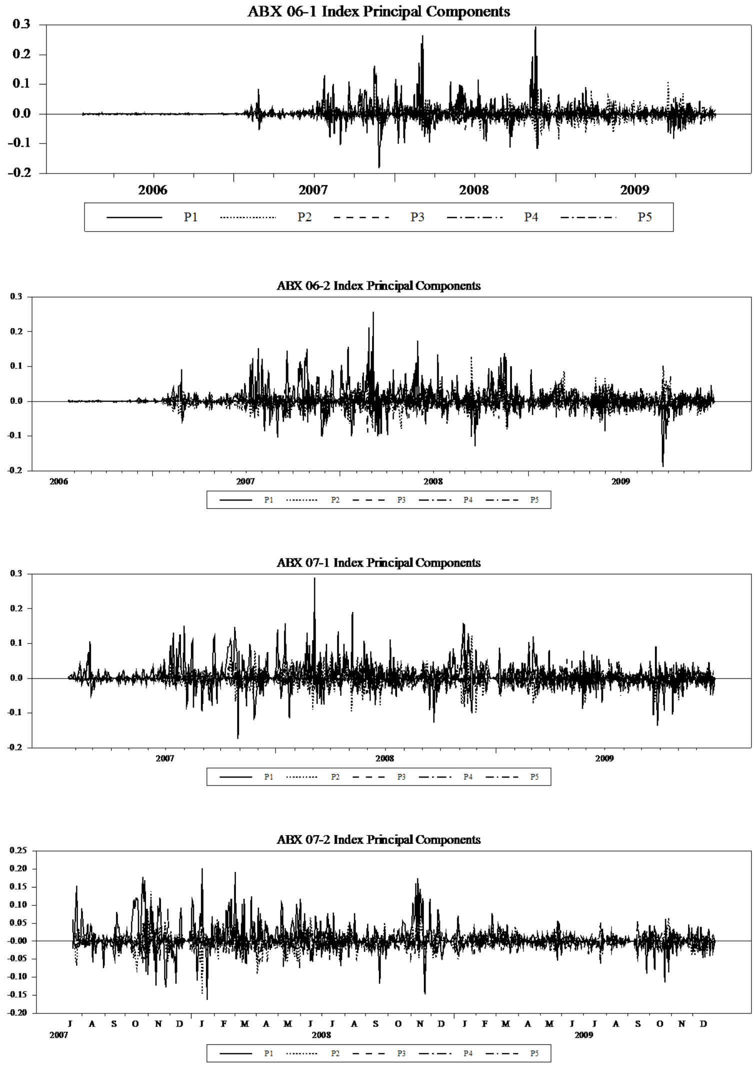


Figure 3.10: Relative Importance of Principal Components by Vintage.
This Figure presents the relative importance of the principal components for the indicated ABX vintage.

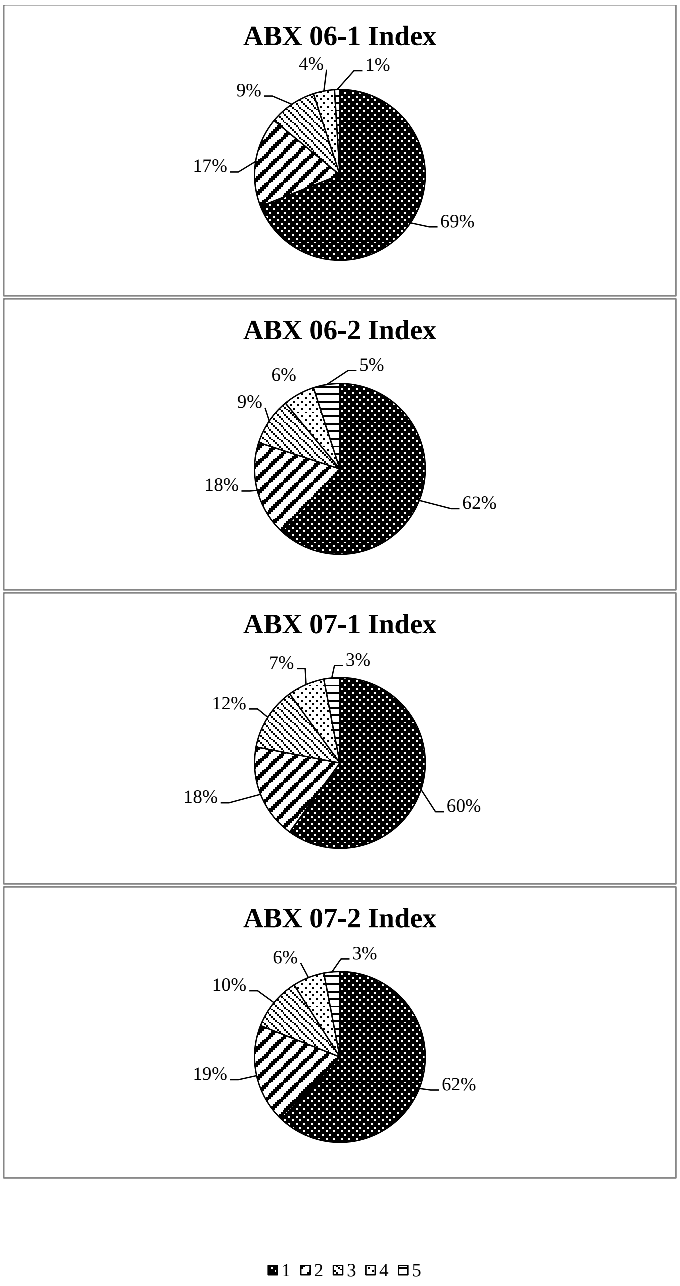


Figure 3.11: Rolling Regression Analysis by Vintage.
Dependent variable: Principal component 1. The horizontal axes labels denote the independent variable employed. Window width = 50. The solid black lines are point estimates; the dashed lines are confidence bands.

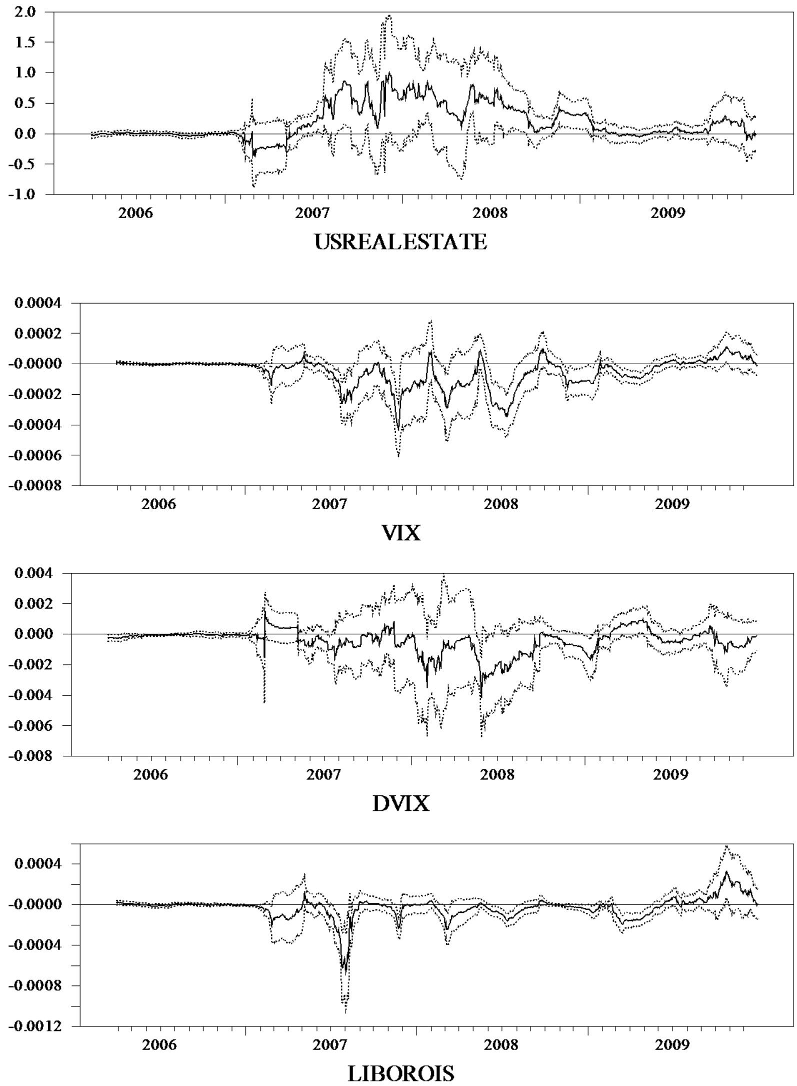


Figure 3.12: Rolling Regression Analysis by Vintage.
Dependent variable: Principal component 1. The horizontal axes labels denote the independent variable employed. Window width = 50. The solid black lines are point estimates; the dashed lines are confidence bands.

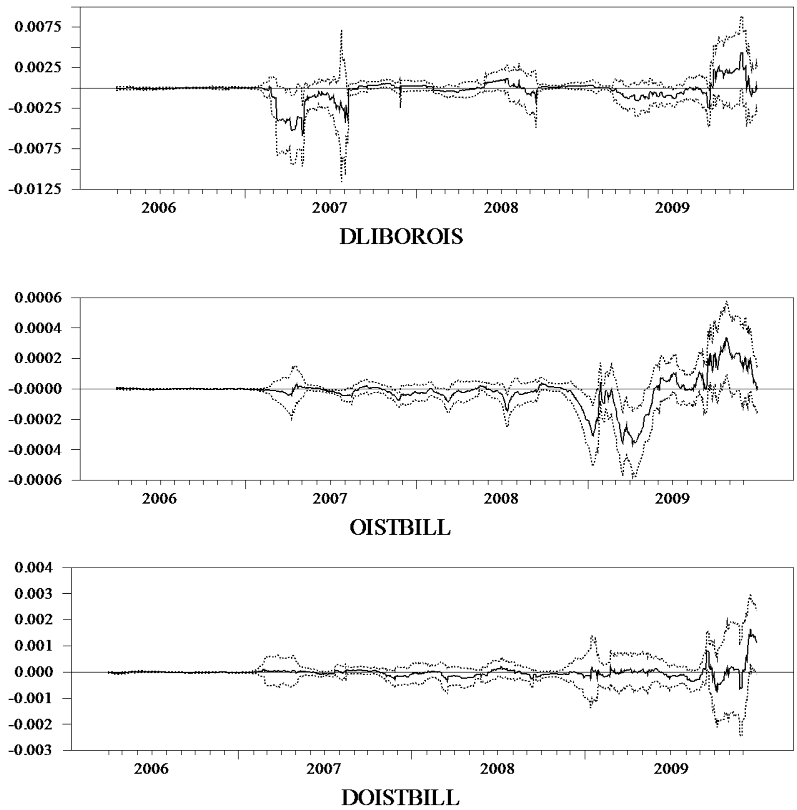


Figure 3.13: Rolling Regression Analysis by Vintage.
Dependent variable: Principal component 2. The horizontal axes labels denote the independent variable employed. Window width = 50. The solid black lines are point estimates; the dashed lines are confidence bands.

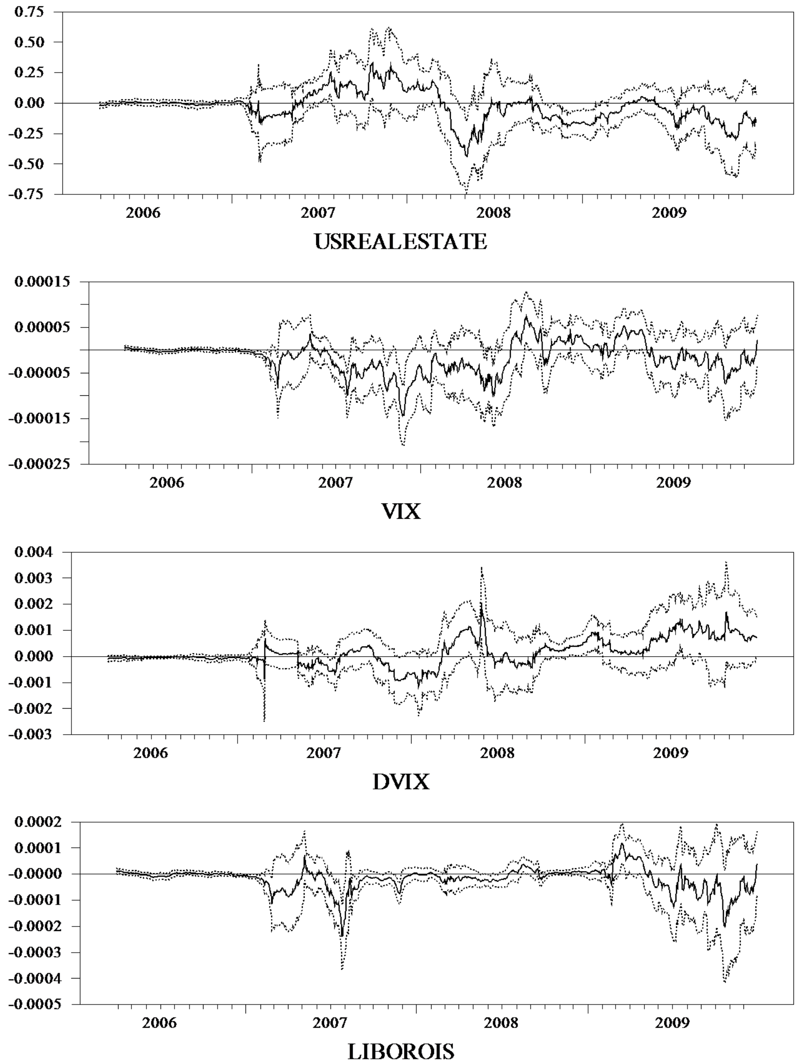


Figure 3.14: Rolling Regression Analysis by Vintage.
Dependent variable: Principal component 2. The horizontal axes labels denote the independent variable employed. Window width = 50. The solid black lines are point estimates; the dashed lines are confidence bands.

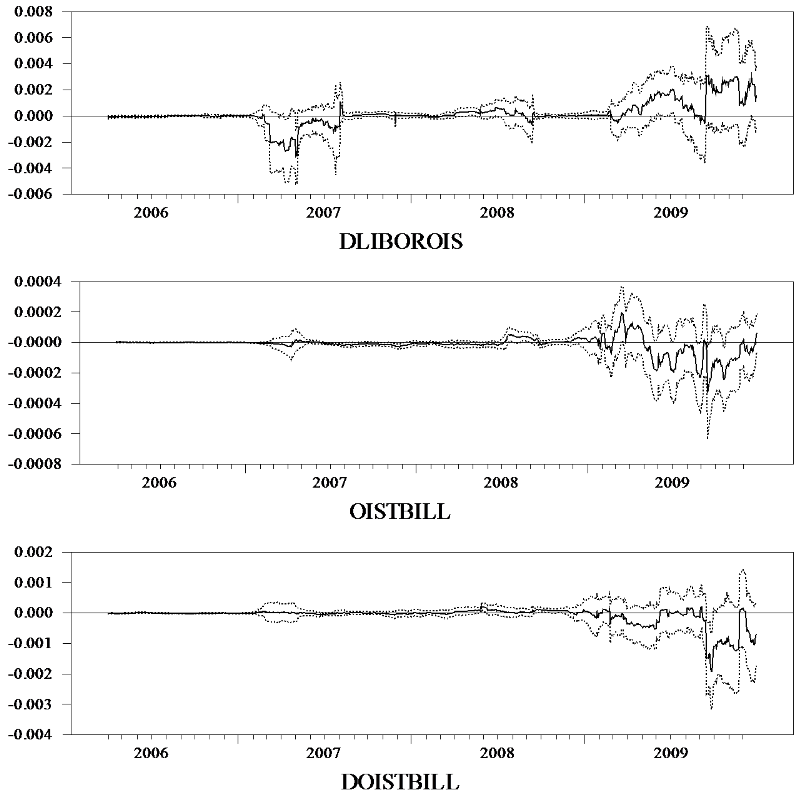


Figure 3.15: Rolling Regression Analysis by Vintage.
Dependent variable: Principal component 3. The horizontal axes labels denote the independent variable employed. Window width = 50. The solid black lines are point estimates; the dashed lines are confidence bands.

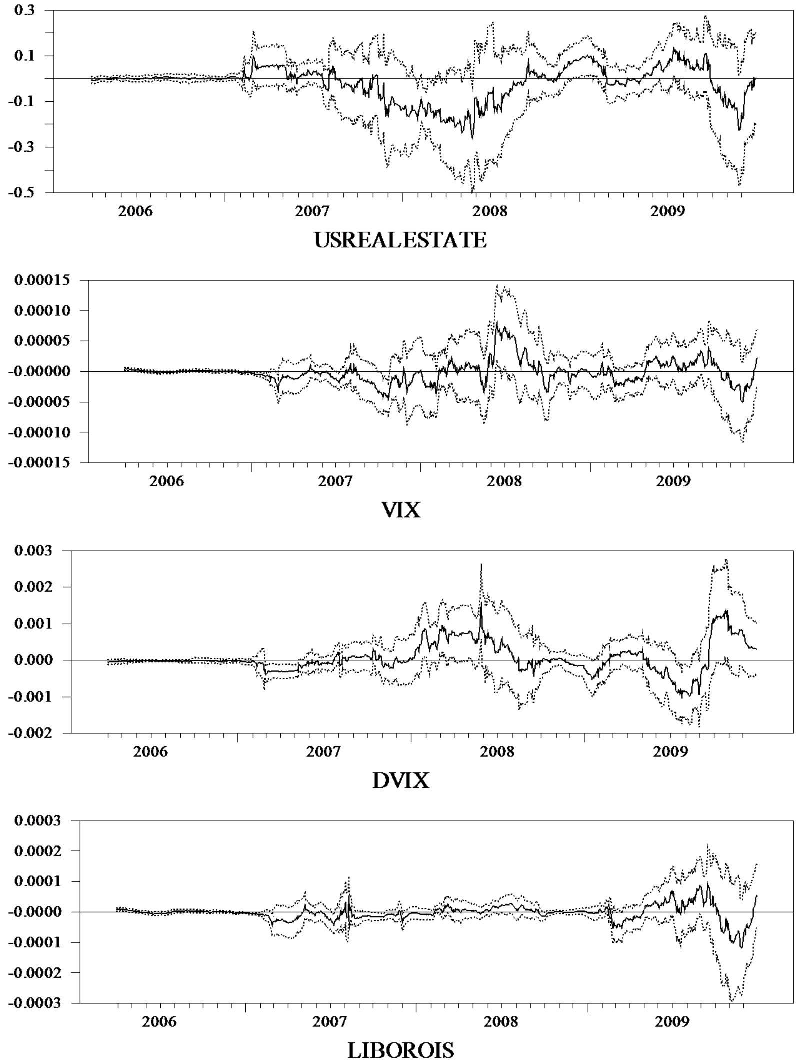


FIGURE 3.16: Rolling Regression Analysis by Vintage.
Dependent variable: Principal component 3. The horizontal axes labels denote the independent variable employed. Window width = 50. The solid black lines are point estimates; the dashed lines are confidence bands.

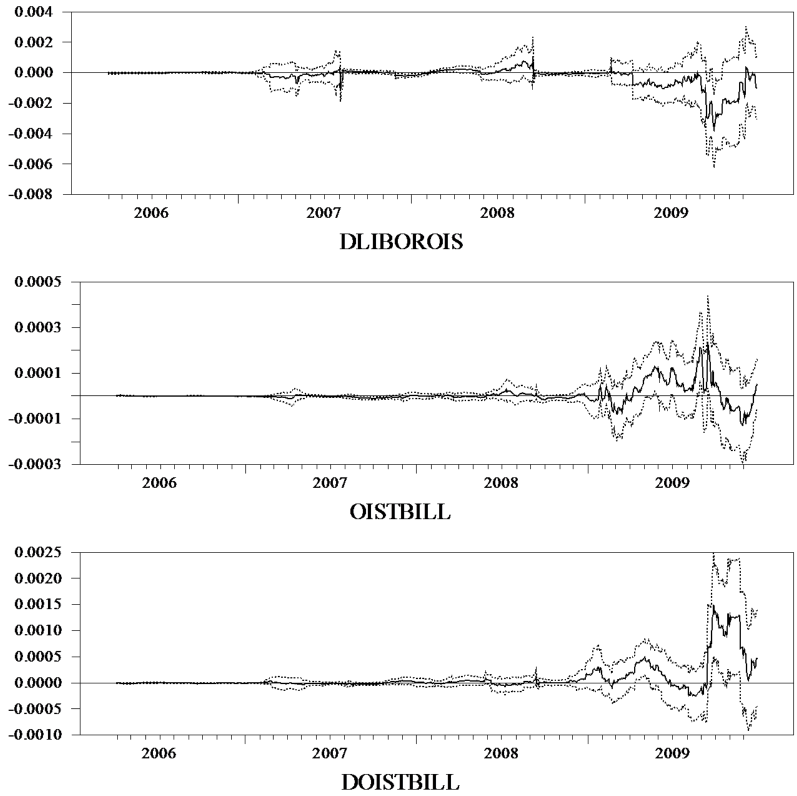


FIGURE 3.17: Relative Importance of Principal Components by Ratings Tranche. This Figure presents the relative importance of the principal components for the indicated ABX ratings tranche.

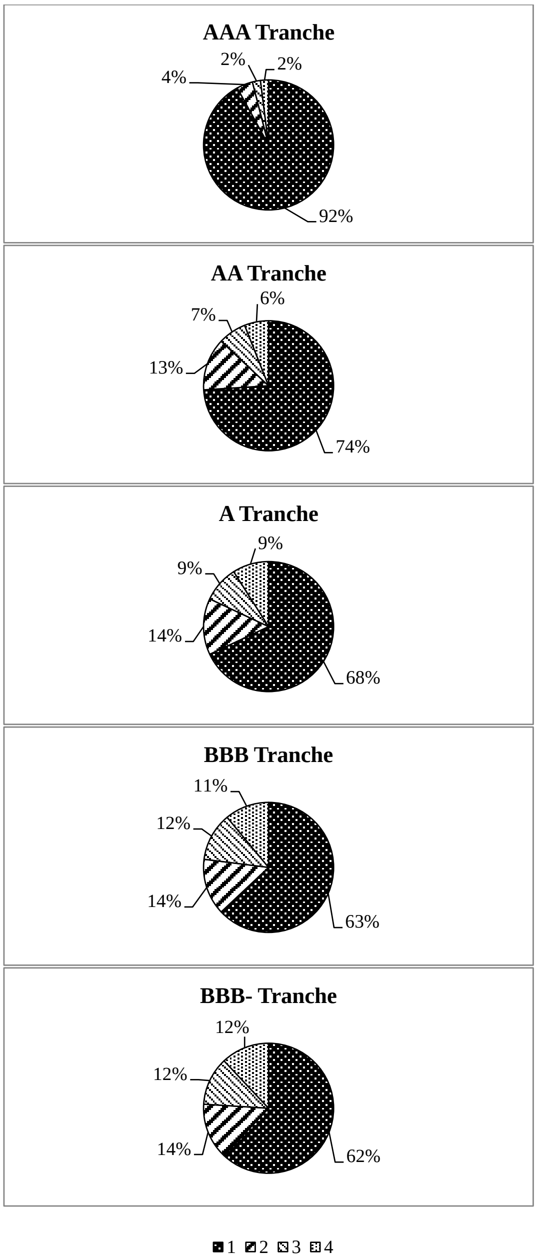


FIGURE 3.18: Rolling Regression Analysis by Ratings Tranche.
Dependent variable: Principal component 1. The horizontal axes labels denote the independent variable employed. Window width = 50. The solid black lines are point estimates; the dashed lines are confidence bands.

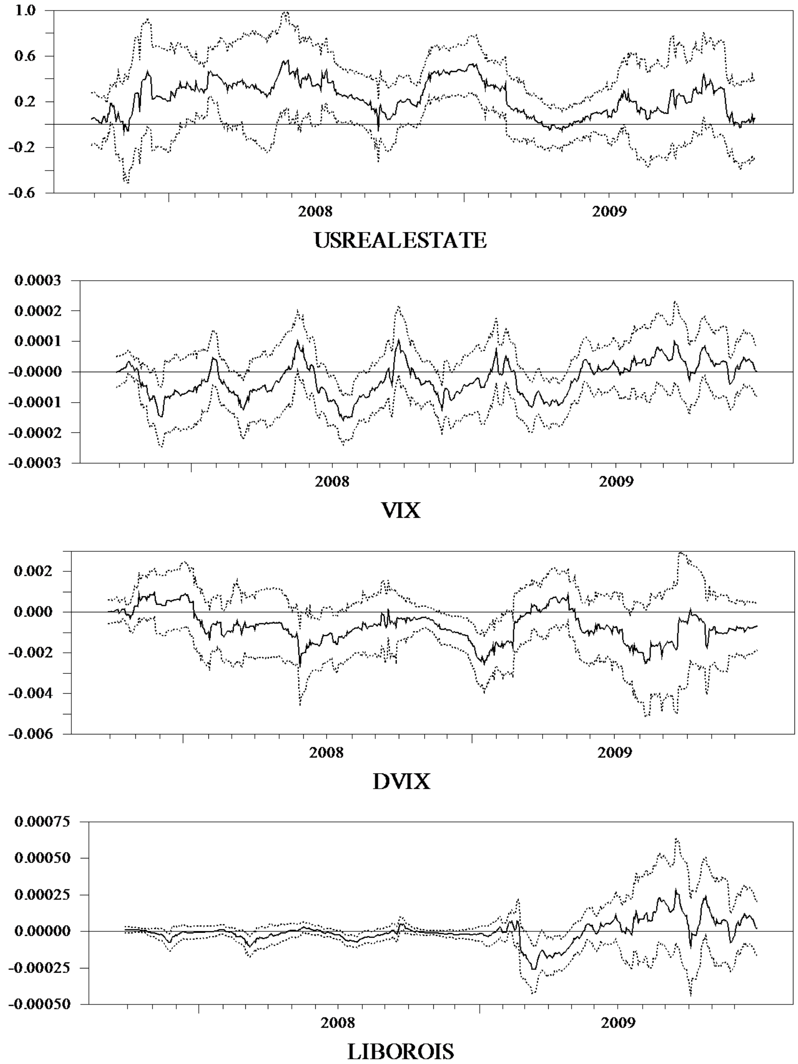


Figure 3.19: Rolling Regression Analysis by Ratings Tranche.
Dependent variable: Principal component 1. The horizontal axes labels denote the independent variable employed. Window width = 50. The solid black lines are point estimates; the dashed lines are confidence bands.

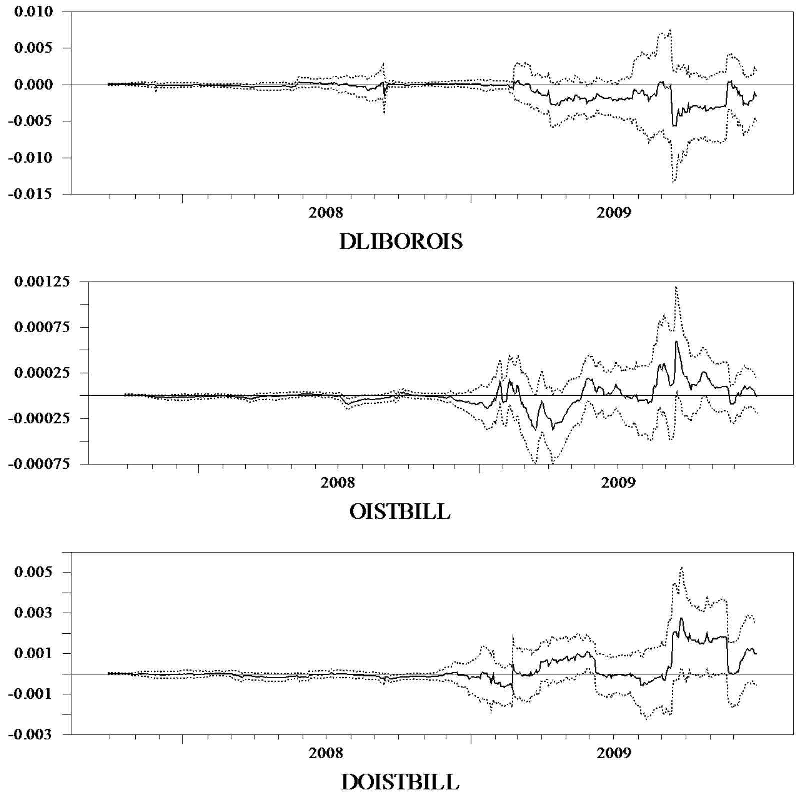


Table 3.1: Timeline Of September 2008 Financial Crisis Events

Notes: This table outlines relevant events related to the financial crisis that occurred in September 2008.

September 2008	Market Events
10th	Lehman announces $ 3.9 billion loss on third quarter.
12th	Moody's and S&P's threaten to downgrade Lehman.
14th	Ten banks create $70 billion liquidity fund.
15th	Bank of America purchases Merrill Lynch.
	Lehman files for bankruptcy.
	AIG debt downgraded by all three major ratings agencies.
16th	RMC money market fund "breaks the buck".
17th	More money market funds come under pressure.
25th	WaMu closed by OTS.
29th	Systemic risk exception allows open bank assistance to Wachovia.

Table 3.2: Summary Statistics For ABX Vintage Daily Returns

Notes: This table reports summary statistics for the daily log returns for the indicated ABX vintage. Std. Dev. denotes standard deviation; Min. denotes minimum; Max. denotes maximum. The sample runs from January 19, 2006 to December 31, 2009.

Index	Rating	Mean	Std.Dev.	Skewness	Kurtosis	Min.	Max.
ABX 06-1 Vintage	AAA	-0.0002	0.0091	-0.8358	18.69	-0.08	0.08
	AA	-0.0012	0.0190	-0.2819	13.53	-0.14	0.14
	A	-0.0023	0.0214	-0.4152	7.548	-0.13	0.10
	BBB	-0.0032	0.0.219	-2.8929	22.640	-0.21	0.11
	BBB-	-0.0031	0.0202	-1.8108	13.92	-0.19	0.11
ABX 06-2 Vintage	AAA	-0.0026	0.0098	-0.7704	15.91	-0.08	0.08
	AA	-0.0014	0.0204	-0.2358	11.42	-0.14	0.14
	A	-0.0027	0.0229	-0.3438	6.209	-0.13	0.10
	BBB	-0.0037	0.0234	-2.6457	19.30	-0.21	0.10
	BBB-	-0.0036	0.0216	-1.6369	11.74	-0.19	0.11
ABX 07-1 Vintage	AAA	-0.0003	0.0106	-0.6995	13.15	-0.08	0.07
	AA	-0.0017	0.0220	-0.1844	9.340	-0.14	0.14
	A	-0.0031	0.248	-0.2635	4.884	-0.13	0.10
	BBB	-0.0043	0.0253	-2.3965	15.99	-0.20	0.10
	BBB-	-0.0042	0.0234	-1.4483	9.569	-0.19	0.11
ABX 07-2 Vintage	AAA	-0.0003	0.0116	-0.6296	10.46	-0.08	0.07
	AA	-0.0020	0.0242	-0.1324	7.280	-0.14	0.14
	A	-0.0035	0.0270	-0.1983	3.679	-0.13	0.10
	BBB	-0.0048	0.0249	-2.2500	13.68	-0.21	0.10
	BBB-	-0.0044	0.0248	-1.3855	8.623	-0.19	0.10

Table 3.3: Correlation Coefficients Between ABX Index Vintages

Notes: This table reports correlation coefficients between the indicated ABX indexes. The sample runs from January 19, 2006 to December 31, 2009.

Correlation coefficient	ABX 06-1	ABX 06-2	ABX 07-1	ABX 07-2
$\rho_{AAA,AA}$	0.83	0.60	0.57	0.60
$\rho_{AAA,A}$	0.49	0.40	0.30	0.40
$\rho_{AAA,BBB}$	0.38	0.22	0.26	0.29
$\rho_{AAA,BBB-}$	0.39	0.19	0.28	0.24
$\rho_{AA,A}$	0.59	0.64	0.55	0.65
$\rho_{AA,BBB}$	0.41	0.43	0.41	0.51
$\rho_{AA,BBB-}$	0.43	0.40	0.40	0.51
$\rho_{A,BBB}$	0.65	0.58	0.53	0.48
$\rho_{A,BBB-}$	0.60	0.51	0.46	0.46
$\rho_{BBB,BBB-}$	0.84	0.74	0.83	0.84

Table 3.4: Summary Statistics For Macroeconomic Variables

Notes: This table reports summary statistics for daily changes of the indicated macroeconomic variable. *REIT* is reported in log returns. δ denotes that the indicated variable is in first differences. Std. Dev. denotes standard deviation; Min. denotes minimum; Max. denotes maximum. The sample runs from January 19, 2006 to December 31, 2009.

Variable	Mean	Std.Dev.	Skewness	Kurtosis	Min.	Max.
REIT	-0.0002	0.0334	-0.0848	6.3288	-0.2148	0.1681
VIX	85.528	47.044	1.6275	2.7708	35.604	291.09
LIBOR-OIS	114.01	169.8	3.4488	14.290	6.3360	1215.9
OIS-Tbill	140.00	138.37	1.5799	2.6010	-30.060	891.00
δVIX	-0.1010	7.9815	0.5259	14.622	-62.496	59.544
δLIBOR-OIS	-0.2628	19.654	-0.0429	26.708	-159.12	181.48
δOIS-Tbill	1.1753	40.785	0.7437	17.255	-268.20	343.08

Table 3.5: OLS Regression Results (Dependent Variables: ABX Returns)

Notes: This table reports OLS regression results for the following equation:

$$ABX_{i,t} = \alpha + \beta_1 REIT_t + \beta_2 VIX_t + \beta_3 LIBOROIS_t + \beta_4 OISTBILL_t + \epsilon_t,$$

in which $ABX_{i,t}$ denotes ABX vintage daily log returns, $REIT$ denotes U.S. real estate investment trust daily log returns, VIX denotes daily VIX volatility index levels, $LIBOROIS$ denotes daily LIBOR-OIS spread levels and $OISTBILL$ denotes daily OIS-Tbill spread level. T-statistics are reported in parentheses. The sample runs from January 19, 2006 to December 31, 2009. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

ABX 06-1 Index						
Dependent	Constant	REIT	VIX	LIBOR-OIS	OIS-Tbill	R^2
AAA	5.12e-04	0.0702**	-1.27e-05	1.08e-06	1.75e-06	0.07
	(0.64)	(8.26)	(-1.51)	(0.41)	(0.70)	
AA	1.42e-03	0.1171**	$-3.56e-05$**	-6.00e-06	7.75e-06	0.06
	(0.89)	(6.58)	(-2.02)	(-1.09)	(1.49)	
A	-1.45e-03	0.0993**	-2.30e-05	-7.47e-06	$1.39e-05$**	0.04
	(-0.80)	(4.90)	(-1.14)	(-1.19)	(2.34)	
BBB	-6.89e-04	0.0618**	$-3.54e-05$	4.18e-06	1.85e-07	0.01
	(-0.37)	(2.94)	(-1.70)	(0.64)	(0.03)	
BBB-	1.67e-05	0.0632**	$-3.65e-05$*	5.31e-06	-4.42e-06	0.02
	(0.01)	(3.26)	(-1.90)	(0.89)	(-0.78)	
ABX 06-2 Index						
Dependent	Constant	REIT	VIX	LIBOR-OIS	OIS-Tbill	R^2
AAA	4.76e-04	0.1179**	-2.10e-05	-2.45e-06	5.69e-06	0.07
	(0.31)	(7.44)	(1.29)	(-0.49)	(1.21)	
AA	-2.04e-03	0.0924**	-1.79e-03	-9.10e-06	$1.52e-06$**	0.04
	(0.99)	(4.40)	(-0.82)	(-1.38)	(2.40)	
A	-2.32e-03	0.0745**	-2.05e-05	2.08e-06	2.21e-e06	0.01
	(-1.00)	(3.12)	(-0.84)	(0.28)	(0.31)	
BBB	-1.61e-03	0.0667	$4.67e-06$	-6.56e-06	-1.06e-05	0.02
	(-0.71)	(0.02)	(0.20)	(0.91)	(-1.53)	
BBB-	-1.31e-03	0.0419*	2.93e-06	-5.96e-05	$-1.29e-05$*	0.02
	(-0.59)	(1.83)	(0.12)	(-0.84)	(-1.90)	
ABX 07-1 Index						
Dependent	Constant	REIT	VIX	LIBOR-OIS	OIS-Tbill	R^2
AAA	-3.30e-04	0.1429**	-1.02e-05	-4.37e-06	-4.37e-06	0.07
	(-0.45)	(7.17)	(-0.46)	(-0.69)	(0.64)	
AA	-2.92e-04	0.1006**	2.19e-05	-5.98e-06	1.10e-05	0.03
	(-1.01)	(3.98)	(-0.78)	(0.75)	(1.42)	
A	-2.35e-03	0.0476*	-1.86e-05	-1.14e-08	-2.54e-e06	0.01
	(-0.75)	(1.73)	(-0.61)	(-0.01)	(-0.30)	
BBB	-2.41e-03	0.0663	4.38e-06	-2.73e-06	$-1.40e-05$*	0.02
	(-0.83)	(0.15)	(0.15)	(-0.34)	(-1.79)	
BBB-	-2.86e-03	0.0524*	8.54e-06	-4.52e-06	$-1.20e-05$*	0.01
	(-1.04)	(2.18)	(0.32)	(-0.60)	(-1.62)	
ABX 07-2 Index						
Dependent	Constant	REIT	VIX	LIBOR-OIS	OIS-Tbill	R^2
AAA	-1.24e-03	0.1385**	-2.07e-06	-5.68e-06	4.95e-06	0.07
	(-0.41)	(6.36)	(-0.08)	(-0.81)	(0.69)	
AA	-4.12e-03	0.1121**	-1.12e-05	-2.60e-06	6.47e-06	0.03
	(-1.09)	(4.13)	(-0.33)	(-0.30)	(0.72)	
A	-1.36e-03	0.0855*	-2.80e-05	3.84e-06	-6.38e-e06	0.02
	(-0.38)	(3.35)	(-0.88)	(0.47)	(-0.76)	
BBB	$-6.91e-03$**	0.0296	2.45e-05	-6.05e-06	3.44e-06	0.003
	(-2.03)	(1.21)	(0.80)	(-0.77)	(0.43)	
BBB-	$-5.81e-03$*	0.0273	1.80e-05	-3.20e-06	-2.76e-07	0.0003
	(-1.69)	(1.11)	(0.59)	(-0.40)	(0.03)	

Table 3.6: OLS Regression Results (Dependent Variables: ABX Returns)

Notes: This table reports OLS regression results for the following equation:

$$ABX_{i,t} = \alpha + \gamma_1 REIT_t + \gamma_2 \delta VIX_t + \gamma_3 \delta LIBOROIS_t + \gamma_4 \delta OISTBILL_t + \epsilon_t,$$

in which $ABX_{i,t}$ denotes ABX vintage daily log returns, $REIT$ denotes U.S. real estate investment trust daily log returns, δVIX denotes daily VIX volatility index changes, $\delta LIBOROIS$ denotes daily LIBOR-OIS spread changes and $\delta OISTBILL$ denotes daily OIS-Tbill spread changes. T-statistics are reported in parentheses. The sample runs from January 19, 2006 to December 31, 2009. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

ABX 06-1 Index						
Dependent	Constant	REIT	δVIX	δLIBOR-OIS	δOIS-Tbill	R^2
AAA	-2.09e-04	0.0711**	-2.42e-06	1.13e-06	-2.20e-06	0.07
	(-0.74)	(6.52)	(-0.05)	(0.08)	(-0.33)	
AA	−0.0012**	0.1108**	-0.00007	-0.0002	-0.00001	0.05
	(-2.06)	(4.82)	(-0.83)	(-0.66)	(-0.75)	
A	−0.0023**	0.0861**	-0.0001	0.00008**	-0.0000005	0.03
	(-3.41)	(3.30)	(-1.19)	(2.46)	(-0.32)	
BBB	−0.0035**	0.0729**	0.00003	0.00008**	-0.0000006	0.02
	(-4.58)	(2.71)	(0.33)	(2.26)	(-0.04)	
BBB-	−0.0031**	0.0689**	0.000007	0.00006**	-0.0000007	0.02
	(-4.83)	(2.77)	(0.07)	(2.14)	(-0.49)	
ABX 06-2 Index						
Dependent	Constant	REIT	δVIX	δLIBOR-OIS	δOIS-Tbill	R^2
AAA	-0.0009	0.1209**	0.000004	-0.00002	-0.00001	0.07
	(-1.62)	(5.90)	(0.05)	(-0.72)	(-0.85)	
AA	−0.0026**	0.0889**	-0.00006	0.00003	-0.00001	0.03
	(-3.48)	(3.23)	(-0.52)	(1.08)	(-0.73)	
A	−0.0036**	0.0781**	0.00001	0.00009**	−0.00003*	0.01
	(-4.28)	(2.55)	(0.11)	(2.29)	(-1.75)	
BBB	−0.0036	0.0699	0.000007	0.00006	-0.00002	0.14
	(-4.31)	(2.33)	(0.06)	(1.51)	(-1.95)	
BBB-	−0.0037**	0.0464	0.00001	0.00004	-0.000008	0.01
	(-4.52)	(1.57)	(0.10)	(0.97)	(-0.42)	
ABX 07-1 Index						
Dependent	Constant	REIT	δVIX	δLIBOR-OIS	δOIS-Tbill	R^2
AAA	−0.0014*	0.1451**	0.000002	-0.00002	-0.0000004	0.07
	(-1.80)	(5.64)	(0.02)	(-0.67)	(-0.67)	
AA	−0.0043**	0.0893**	-0.0001	0.00004	0.000002	0.03
	(-4.42)	(2.73)	(-0.81)	(1.06)	(0.47)	
A	−0.0046**	0.0419	-0.00007	0.0008*	0.000002	0.01
	(-4.37)	(1.18)	(-0.44)	(1.85)	(0.11)	
BBB	−0.0045**	0.0921**	0.00016	0.00004	-0.000006	0.01
	(-4.65)	(2.81)	(1.16)	(0.99)	(-0.33)	
BBB-	−0.0045**	0.0723*	0.0001	0.00003	-0.00002	0.01
	(-4.90)	(2.35)	(1.04)	(0.83)	(-1.08)	
ABX 07-2 Index						
Dependent	Constant	REIT	δVIX	δLIBOR-OIS	δOIS-Tbill	R^2
AAA	−0.0017*	0.1375**	-0.000009	-0.00004	-0.000009	0.07
	(-1.80)	(4.89)	(-0.08)	(-1.51)	(-0.52)	
AA	−0.0047**	0.0949**	-0.0001	-0.0000002	0.00001	0.03
	(-4.23)	(2.71)	(-0.89)	(-0.01)	(0.64)	
A	-0.0047	0.0899*	-0.000002	0.00006	0.000008	0.02
	(-0.48)	(2.74)	(-0.01)	(1.57)	(0.40)	
BBB	−0.0047**	0.03223	0.00002	-0.00003	0.00001	0.004
	(-4.61)	(1.02)	(0.17)	(-0.66)	(0.67)	
BBB-	−0.004**	0.0261	-0.000009	-0.000006	0.00002	0.003
	(-4.28)	(0.82)	(-0.07)	(-0.14)	(0.96)	

Table 3.7: OLS Regression Results (Dependent Variables: Principal Components)

Notes: This table reports OLS regression results for the following equation:

$$PrincipalComponent_{i,t} = \alpha + \beta_1 REIT_t + \beta_2 VIX_t + \beta_3 LIBOROIS_t + \beta_4 OISTBILL_t + \epsilon_t,$$

in which PC_i denotes the principal component included as the dependent variable, $REIT$ denotes U.S. real estate investment trust daily log returns, VIX denotes daily VIX volatility index levels, $LIBOROIS$ denotes daily LIBOR-OIS spread levels and $OISTBILL$ denotes daily OIS-Tbill spread level. T-statistics are reported in parentheses. The sample runs from January 19, 2006 to December 31, 2009. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

			ABX 06-1 Index			
Dependent	Constant	REIT	VIX	LIBOR-OIS	OIS-Tbill	R^2
PC_1	-4.63e-04	0.1729**	$-6.53e-05^{*}$	-9.68e-07	8.07e-06	0.04
	(-0.15)	(5.19)	(-1.97)	(-0.09)	(0.83)	
PC_2	-1.03e-03	-0.0765^{**}	4.61e-06	$9.86e-06^{*}$	$1.14e-05^{**}$	0.03
	(-0.69)	(-4.59)	(0.28)	(1.91)	(-2.34)	
PC_3	$1.84e-03^{*}$	0.0154	-1.53e-05	5.60e-06	$-8.52e-06^{**}$	0.01
	(1.72)	(1.29)	(-1.28)	(1.51)	(-2.43)	
			ABX 06-2 Index			
Dependent	Constant	REIT	VIX	LIBOR-OIS	OIS-Tbill	R^2
PC_1	-0.0034	0.1597**	-0.00002	-0.000009	-0.000003	0.03
	(-0.93)	(4.20)	(-0.48)	(-0.80)	(-0.28)	
PC_2	1.46e-04	0.0749**	-2.84e-05	4.04e-07	$2.23e-05^{**}$	0.04
	(0.07)	(3.60)	(-1.33)	(0.06)	(3.61)	
PC_3	8.89e-04	0.0465**	-7.65e-06	-7.645e-06	9.44e-07	0.02
	(0.64)	(3.24)	(0.09)	(0.09)	(0.22)	
			ABX 07-1 Index			
Dependent	Constant	REIT	VIX	LIBOR-OIS	OIS-Tbill	R^2
PC_1	-0.0050	0.1657**	-0.00002	-0.000007	-0.000008	0.03
	(-1.05)	(3.93)	(-0.34)	(-0.55)	(-0.62)	
PC_2	-3.23e-04	-000727^{**}	2.61e-05	1.89e-06	$-1.99e-05^{**}$	0.03
	(-4.42)	(2.73)	(-0.81)	(1.06)	(2.47)	
PC_3	-5.08e-06	-0.0785^{**}	-8.24e-06	4.86e-06	-9.06e-07	0.02
	(-0.01)	(-4.02)	(-0.38)	(0.80)	(-0.15)	
			ABX 07-2 Index			
Dependent	Constant	REIT	VIX	LIBOR-OIS	OIS-Tbill	R^2
PC_1	-0.0890	0.1704**	-0.0000006	-0.000005	0.000003	0.03
	(-1.49)	(3.93)	(-0.01)	(-0.39)	(0.24)	
PC_2	3.99e-03	0.1059**	-3.32e-05	1.68e-06	2.23e-06	0.04
	(1.19)	(4.38)	(-1.11)	(0.21)	(0.28)	
PC_3	-2.00e-03	0.0357*	2.66e-05	-8.04e-06	8.84e-06	0.01
	(-0.80)	(1.99)	(1.19)	(-1.39)	(1.50)	

Table 3.8: OLS Regression Results (Dependent Variables: Principal Components)

Notes: This table reports OLS regression results for the following equation:

$$PC_{i,t} = \alpha + \gamma_1 REIT_t + \gamma_2 \delta VIX_t + \gamma_3 \delta LIBOROIS_t + \gamma_4 \delta OISTBILL_t + \epsilon_t,$$

in which PC_i denotes the principal component included as the dependent variable, $REIT$ denotes U.S. real estate investment trust daily log returns, VIX denotes daily VIX volatility index levels, $LIBOROIS$ denotes daily LIBOR-OIS spread levels and $OISTBILL$ denotes daily OIS-Tbill spread level. δ denotes that the indicated variable is differenced. T-statistics are reported in parentheses. The sample runs from January 19, 2006 to December 31, 2009. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

			ABX 06-1 Index			
Dependent	Constant	REIT	δVIX	δLIBOR-OIS	δOIS-Tbill	R^2
PC_1	-0.0050^{**}	0.1728^{**}	-0.00007	0.0001^{**}	-0.00001	0.03
	(-4.54)	(4.03)	(-0.41)	(2.06)	(-0.43)	
PC_2	-0.0011^{**}	-0.0616^{**}	0.0001	0.00005^{*}	0.000006	0.03
	(-1.99)	(-2.88)	(1.24)	(1.92)	(0.47)	
PC_3	-2.08e-05	0.0262^{*}	7.26e-05	$-4.51e-06^{**}$	-3.48e-06	0.01
	(-0.05)	(1.70)	(1.14)	(-2.31)	(-0.37)	
			ABX 06-2 Index			
Dependent	Constant	REIT	δVIX	δLIBOR-OIS	δOIS-Tbill	R^2
PC_1	-0.0068^{**}	0.1638^{**}	-0.000009	0.0001^{*}	-0.000003	0.03
	(-5.06)	(3.35)	(-0.04)	(1.72)	(-0.28)	
PC_2	0.006	0.0708^{**}	-0.00004	-0.000008	$2.23e-05^{**}$	0.02
	(0.75)	(2.61)	(-0.34)	(-0.51)	(3.61)	
PC_3	0.0002	0.0448^{**}	-0.00003	0.00001	9.44e-07	0.02
	(0.34)	(2.40)	(-0.34)	(1.19)	(0.22)	
			ABX 07-1 Index			
Dependent	Constant	REIT	δVIX δ	LIBOR-OIS	δOIS-Tbill	R^2
PC_1	-0.0089^{**}	0.1817^{**}	0.00006	0.00009	-0.000008	0.02
	(-5.55)	(3.34)	(0.28)	(1.35)	(-0.24)	
PC_2	-0.0005	-0.0441	0.0002^{*}	0.000006	-0.00002	0.02
	(-0.55)	(-1.44)	(1.65)	(0.16)	(-0.90)	
PC_3	-0.0003	-0.0908^{**}	0.000009	0.00005^{*}	0.000009	0.03
	(-0.35)	(-3.61)	(-0.84)	(1.68)	(0.57)	
			ABX 07-2 Index			
Dependent	Constant	REIT	δVIX	δLIBOR-OIS	δOIS-Tbill	R^2
PC_1	-0.0093^{**}	0.1638^{**}	-0.00007	0.000003	0.00002	0.03
	(-5.19)	(2.93)	(-0.26)	(0.04)	(0.66)	
PC_2	0.0009	0.0988^{**}	-0.00006	0.000009	0.00001	0.03
	(0.97)	(3.16)	(-0.48)	(0.24)	(-0.70)	
PC_3	0.0091	0.0312	-0.000008	-0.00008^{**}	-0.000006	0.02
	(1.24)	(1.35)	(-0.08)	(-2.73)	(-0.39)	

TABLE 3.9: Correlation Coefficients Between Macroeconomic Variables

Notes: This table reports correlation coefficients between the indicated macroeconomic variables. The sample runs from January 19, 2006 to December 31, 2009.

$\rho_{REIT,VIX}$	0.10	$\rho_{REIT,\delta VIX}$	-0.62
$\rho_{REIT,LIBOROIS}$	-0.07	$\rho_{REIT,\delta LIBOROIS}$	-0.03
$\rho_{REIT,OISTBILL}$	-0.01	$\rho_{REIT,\delta OISTBILL}$	-0.05
$\rho_{VIX,\delta VIX}$	0.09	$\rho_{VIX,LIBOROIS}$	0.64
$\rho_{VIX,\delta LIBOROIS}$	-0.05	$\rho_{VIX,OISTBILL}$	0.04
$\rho_{VIX,\delta OISTBILL}$	0.01	$\rho_{\delta VIX,LIBOROIS}$	0.06
$\rho_{\delta VIX,\delta LIBOROIS}$	0.19	$\rho_{\delta VIX,OISTBILL}$	0.03
$\rho_{\delta VIX,\delta OISTBILL}$	0.11	$\rho_{LIBOROIS,\delta LIBOROIS}$	0.06
$\rho_{LIBOROIS,OISTBILL}$	0.46	$\rho_{LIBOROIS,\delta OISTBILL}$	-0.04
$\rho_{OISTBILL,\delta OISTBILL}$	0.16		

Table 3.10: Summary Statistics For ABX Tranche Daily Returns

Notes: This table reports summary statistics for the daily log returns for the indicated ABX vintage ratings tranche. Std. Dev. denotes standard deviation; Min. denotes minimum; Max. denotes maximum. The sample runs from January 19, 2006 to December 31, 2009.

AAA tranche						
Index	Mean	Std.Dev.	Skewness	Kurtosis	Min.	Max.
ABX 06-1 Vintage	-0.0003	0.0116	-0.6285	10.5	-0.08	0.08
ABX 06-2 Vintage	-0.0013	0.0200	-0.2806	4.03	-0.08	0.11
ABX 07-1 Vintage	-0.0017	0.0232	-0.0229	5.06	-0.11	0.14
ABX 07-2 Vintage	-0.0017	0.0228	0.0570	6.02	-0.10	0.14
AA tranche						
Index	Mean	Std.Dev.	Skewness	Kurtosis	Min.	Max.
ABX 06-1 Vintage	-0.0020	0.0241	-0.1330	7.27	-0.14	0.14
ABX 06-2 Vintage	-0.0036	0.0263	-0.1564	3.67	-0.11	0.13
ABX 07-1 Vintage	-0.0051	0.0286	-0.7202	3.88	-0.16	0.10
ABX 07-2 Vintage	-0.0049	0.0279	0.8774	5.76	-0.14	0.15
A tranche						
Index	Mean	Std.Dev.	Skewness	Kurtosis	Min.	Max.
ABX 06-1 Vintage	-0.0036	0.0270	-0.1956	3.68	-0.13	0.10
ABX 06-2 Vintage	-0.0047	0.0290	-0.7942	4.38	-0.17	0.10
ABX 07-1 Vintage	-0.0050	0.0307	-0.7991	4.10	-0.19	0.09
ABX 07-2 Vintage	-0.0048	0.0261	-0.6280	3.50	-0.14	0.09
BBB tranche						
Index	Mean	Std.Dev.	Skewness	Kurtosis	Min.	Max.
ABX 06-1 Vintage	-0.0048	0.0273	-2.2431	13.6	-0.21	0.11
ABX 06-2 Vintage	-0.0041	0.0275	-0.0847	5.49	-0.13	0.18
ABX 07-1 Vintage	-0.0043	0.0271	-0.7815	5.46	-0.18	0.10
ABX 07-2 Vintage	-0.0047	0.0248	-1.1982	7.99	-0.20	0.09
BBB- tranche						
Index	Mean	Std.Dev.	Skewness	Kurtosis	Min.	Max.
ABX 06-1 Vintage	-0.0043	0.0246	-1.3696	8.81	-0.19	0.11
ABX 06-2 Vintage	-0.0039	0.0265	0.0755	2.94	-0.11	0.12
ABX 07-1 Vintage	-0.0041	0.0256	-0.8406	5.41	-0.18	0.09
ABX 07-2 Vintage	-0.0044	0.0250	-.8637	4.82	-0.16	0.09

Table 3.11: Correlation Coefficients Between ABX Index Tranches

Notes: This table reports correlation coefficients between the indicated ABX index rating tranche. The sample runs from January 19, 2006 to December 31, 2009.

$\rho_{AAA0601,AAA0602}$	0.87	$\rho_{AAA0601,AAA0701}$	0.81
$\rho_{AAA0601,AAA0702}$	0.81	$\rho_{AAA0602,AAA0701}$	0.89
$\rho_{AAA0602,AAA0702}$	0.87	$\rho_{AAA0701,AAA0702}$	0.93
$\rho_{AA0601,AA0602}$	0.61	$\rho_{AA0601,AA0701}$	0.51
$\rho_{AA0601,AA0702}$	0.51	$\rho_{AA0602,AA0701}$	0.52
$\rho_{AA0602,AA0702}$	0.68	$\rho_{AA0701,AA0702}$	0.60
$\rho_{A0601,A0602}$	0.64	$\rho_{A0601,A0701}$	0.49
$\rho_{A0601,A0702}$	0.56	$\rho_{A0602,A0701}$	0.59
$\rho_{A0602,A0702}$	0.60	$\rho_{A0701,A0702}$	0.57
$\rho_{BBB0601,BBB0602}$	0.51	$\rho_{BBB0601,BBB0701}$	0.47
$\rho_{BBB0602,BBB0702}$	0.49	$\rho_{BBB0602,BBB0701}$	0.58
$\rho_{BBB0602,BBB0702}$	0.51	$\rho_{BBB0701,BBB0702}$	0.50
$\rho_{BBB-0601,BBB-0602}$	0.49	$\rho_{BBB-0601,BBB-0701}$	0.51
$\rho_{BBB-0601,BBB-0702}$	0.45	$\rho_{BBB-0602,BBB-0701}$	0.54
$\rho_{BBB-0602,BBB-0702}$	0.44	$\rho_{BBB-0701,BBB-0702}$	0.49

TABLE 3.12: OLS Regression Results (Dependent Variables: Principal Components)

Notes: This table reports OLS regression results for the following equations:

$$PC_{i,t} = \alpha + \beta_1 REIT_t + \beta_2 VIX_t + \beta_3 LIBOROIS_t + \beta_4 OISTBILL_t + \epsilon_t,$$

and

$$PC_{i,t} = \alpha + \gamma_1 REIT_t + \gamma_2 \delta VIX_t + \gamma_3 \delta LIBOROIS_t + \gamma_4 \delta OISTBILL_t + \epsilon_t,$$

in which $PC_{i,t}$ denotes the principal component included as the dependent variable, $REIT$ denotes U.S. real estate investment trust daily log returns, VIX denotes daily VIX volatility index levels, $LIBOROIS$ denotes daily LIBOR-OIS spread levels and $OISTBILL$ denotes daily OIS-Tbill spread level. δ denotes that the indicated variable is differenced. T-statistics are reported in parentheses. The sample runs from January 19, 2006 to December 31, 2009. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

AAA-Rated Tranche						
Dependent	Constant	REIT	VIX	LIBOR-OIS	OIS-Tbill	R^2
PC_1	-0.0004	0.2462**	-0.00002	-0.000007	-0.000009	0.08
	(-0.09)	(6.77)	(-0.48)	(-0.60)	(0.75)	
PC_2	$-1.88e-03$*	-4.23e-03	$2.06e-05$**	-2.88e-06	-1.06e-06	0.01
	(-1.65)	(-0.51)	(2.02)	(-1.09)	(-0.39)	
PC_3	1.14e-04	-5.97e-04	-7.33e-07	-4.25e-07	-7.62e-08	0.0001
	(0.14)	(-0.10)	(-0.10)	(0.22)	(-0.04)	
PC_4	-6.28e-04	-7.14e-03	4.30e-06	-2.45e-06	1.71e-06	0.01
	(-0.92)	(-1.46)	(0.71)	(-1.55)	(1.06)	

AAA-Rated Tranche						
Dependent	Constant	REIT	δVIX	δLIBOR-OIS	δOIS-Tbill	R^2
PC_1	-0.0026*	0.2480**	-0.000008	-0.00004	-0.00001	0.08
	(-1.70)	(5.28)	(-0.04)	(-0.76)	(-0.49)	
PC_2	-2.96e-04	-6.74e-03	-5.08e-06	-1.40e-05	3.15e-06	0.003
	(-0.86)	(-0.63)	(-0.11)	(-1.06)	(-0.48)	
PC_3	9.10e-05	-1.91e-03	-5.92e-06	-8.27e-06	-2.57e-06	0.002
	(0.37)	(-0.25)	(-0.18)	(-0.88)	(-0.55)	
PC_4	-2.99e-04	-6.99e-03	3.47e-03	$-1.30e-06$*	-4.32e-06	0.01
	(-1.48)	(-1.11)	(0.13)	(-1.66)	(-1.11)	

Chapter 4

Analysing Contagion Within the U.S. Subprime Mortgage-Backed Securities Market

4.1. Introduction

In 2007 the United States' financial system was hit by its worst crisis in almost a century, one that led the global economy into what has been dubbed the "Great Recession" by former Federal Reserve chairman Paul Volcker (Cetorelli et al., 2012). Between October 2007 and March 2009 the S&P 500 lost approximately 56% of its value, in November 2008 the Chicago Board Options Exchange Volatility Index (VIX) increased steadily to an historical high of 80.86 percentage points, and it has been estimated that global losses due to the crisis will amount to over $12 trillion (Better Markets Report, September 2012).

As the crisis unfolded many attributed U.S. subprime mortgage-backed securities as the underlying source of the problem, such as Gorton (2009), Brunnermeier (2008) and Mah-Hui (2008). The fledgling market for these structured finance products had experienced rapid growth in the years prior to the crisis, trading not only in the United States but by investors across the globe (Dodd, 2007). The tranche and ratings features of these asset-backed securities appealed to investors as a means of spreading risk, and soon suppliers of subprime mortgage-backed products were struggling to meet the increasing demand for them, leading to lax loan standards and feeding market growth even more (Mian & Sufi, 2009). The share of subprime mortgages increased from approximately 9% of new mortgages in the early 2000s to over 40% in 2006 (Hellwig, 2009) and subprime mortgage-backed security issuance grew from $195 billion to

$362.5 billion during the same period (Park, 2010).

The growth of this market led to the creation of the ABX.HE indexes, which reference subprime mortgage-backed collateralized debt obligations (CDOs).[1] With the decline of the real estate market in early 2007 things began to unravel rapidly as the threat of vast defaults in the subprime mortgage market led investors to reassess the risk of these asset-backed securities (Fender & Scheicher, 2008). Soon it became clear that in most cases there had been a gross underestimation of this risk, resulting in vast mispricing of these products (Whetten, 2006). This created widespread panic for the large number of investors trading them and in most cases the originating financial institutions were forced to take them back onto their books, resulting in warehousing risk and substantial losses (Purnanandam, 2011). This financial market distress fuelled a lack of trust between financial institutions, as many were unsure of even their own exposure to these now "toxic" products, and so could not be confident of other institutions exposures. This led to a widespread credit crunch in 2008, with September of that year seen by many as a turning point in the crisis (Longstaff, 2010). Events such as the collapse of Lehman Brothers and the acquisition of Merrill Lynch by Bank of America caused further distress in already unstable markets as stock prices plummeted and liquidity came to a halt.

Contagion in financial markets during a crisis such as that experienced in 2007-2009 is important to both investors and financial institutions keen to halt the spread of crises and so this chapter tests for contagion within the U.S. subprime mortgage-backed securities sector using the ABX indexes to represent this market. As Longstaff (2010) tests for contagion from the ABX indexes to other financial markets during the crisis that work is treated as a basis for this chapter. However, as this chapter deals with

[1] For a detailed discussion of the ABX please refer to Chapter 2, section 2.3.1.

the ABX market only, we modify the definition of contagion used by Longstaff (2010), which is that presented by Forbes & Rigobon (2002), to "an episode in which there is a significant increase in intra-market linkages after a shock occurs in that market". Because we are testing for significant changes in existing linkages we are therefore testing for a form of shift contagion and define contagion as linkages over and above those experienced during "normal" market conditions.[2]

Following and modifying the VAR framework outlined in Longstaff (2010) we test if returns in the ABX assets Granger-cause returns in other assets during the crisis period. We then analyse the sum of lagged coefficients in order to ascertain if identified shocks are short-lived or persistent in nature. The analysis is performed on the spliced ABX index employed by Longstaff (2010) and two traded ABX vintages to investigate if the results vary substantially across indexes.[3]

The results provide evidence for contagion within the three ABX indexes analysed during the volatile 2007 "subprime-crisis" period which then dissipates during the 2008 "global-crisis" period, as liquidity came to a halt, before increasing slightly during the "post-crisis" period of 2009, as markets rebounded. The higher-rated assets display more evidence of contagion than the lower ratings, which may be due to the effect of the common shock transferring risk from the lower to the higher rating classes. Persistent shocks emanate from the higher-rated assets in the traded vintages but from the lower ratings in the spliced ABX index, indicating that combining the four ABX vintages to create an on-the-run spliced ABX index may influence results. The results also vary across the traded ABX vintages, suggesting that these assets were heterogeneous in

[2]Shift contagion is defined as a change in existing relationships between markets during crisis times while pure contagion is that unrelated to fundamentals, in other words a relationship that did not exist prior to the crisis period.

[3]Note that "spliced ABX index" refers to the ABX series constructed in Longstaff (2010) while the terms "ABX 06-1 index/vintage", "ABX 06-2 index/vintage", "ABX 07-1 index/vintage", "ABX 07-2 index/vintage" refer to the traded ABX issuances.

nature.

The remainder of the chapter is organised as follows. Section 4.2 briefly describes the literature analysing the ABX indexes in terms of both contagion and analysis of the indexes themselves. Section 4.3 describes the data employed and the VAR framework used. Section 4.4 presents preliminary data analysis while section 4.5 provides results from the VAR analysis. Section 4.6 then presents those obtained from a modified VAR analysis. A final section concludes.

4.2. Related Literature

The first two ABX vintages began trading in 2006 and soon became key measures of subprime mortgage market conditions for investors and financial institutions (Marques-Ibanez & Scheicher, 2009). As the crisis of 2007 unfolded many turned to this proxy for the subprime mortgage-backed securities market in order to shed light upon what had led the financial system to such a collapse. Gorton (2009) states that the ABX lay at the very heart of the crisis and suggests that trades in the indexes caused information regarding the decline of house prices to be exposed, revealing how interlinked the housing market and the market for these securities had become. The creation of this "common knowledge" fuelled the widespread panic that led to the liquidity crisis of 2008, causing the ABX to become the central point of the crisis.

Stanton & Wallace (2011) investigate whether ABX prices efficiently aggregate information regarding the credit performance of referenced subprime mortgage obligations and conclude that the indexes are in fact an imperfect benchmark for marking-to-market mortgage portfolios. Caruana & Kodres (2008) highlight that the over-the-counter (OTC) characteristics of ABX trading contributed to the opaque nature of the market. They suggest that price behaviour of the ABX implies that these products were used in place of actual liquid securities to absorb new information. Whetten (2006) highlights the differences between corporate credit default swaps and asset-backed credit default swaps and describes how the ABX enabled investors to convey their view of the subprime mortgage-backed security sector by taking a position in a credit default swap.

Despite a vast literature analysing the transmission of shocks across countries and markets there is little consensus regarding exactly what constitutes financial contagion. Early work, such as King & Wadwani (1990), Lee & Kim (1993) and Calvo & Reinhart (1996), fail to differentiate between contagion and interdependencies that occur between financial markets even in "normal" market conditions. In their seminal paper analysing this problem Forbes & Rigobon (2002) show that tests for contagion based on correlation coefficients alone provide misleading and biased results as they do not correct for heteroskedasticity in market returns. Analysing three crises they propose a correction for this bias, concluding that if there is no significant increase in co-movement over and above what is experienced in tranquil times it is interdependence, not contagion, observed in markets.

Although there is a large body of work analysing contagion in financial markets literature utilizing the ABX indexes to test for its presence during the crisis of 2007-2009 is not as extensive, and, as yet, there are no published works analysing contagion within the ABX itself. Longstaff (2010) utilizes the ABX indexes to represent the U.S. subprime mortgage-backed securities market and tests for contagion from this market to several fixed income, equity and volatility markets using a vector autoregressive (VAR) framework.

Longstaff (2010) highlights that the literature examining contagion broadly classifies three potential devices though which contagion may be transmitted to financial markets. The first mechanism is termed the "correlated-information channel". In this channel contagion occurs through the transmission of information by means of price discovery and should cause instantaneous price effects following a crisis. The second channel presented is known as the "liquidity channel". This channel implies that a crisis be related to credit shortages and increased trading in other financial markets. The third outlet is labelled the "risk-premium channel" through which shocks to an affected security may have predictive ability for subsequent returns of other securities. Using a VAR framework Longstaff (2010) finds strong evidence of contagion in the financial markets examined over the crisis period. It is also found that this contagion is mainly transmitted through liquidity and risk-premium channels, rejecting the correlated information channel. Significant price discovery supports this hypothesis.

4.3. Data

This chapter uses the spliced ABX index employed by Longstaff (2010) as a benchmark case for testing for contagion within the indexes.[4] These results are then compared to those obtained using the traded ABX 06-1 and 06-2 vintages in order to ascertain if there exist significant differences between vintages and also if splicing the data could

[4]The spliced ABX index is defined in the following section

influence results.[5] ABX data have been obtained from the Markit Group Ltd. and weekly (Wednesday to Wednesday) percentage changes are used in the analysis.

The sample period ranges from January 19, 2006, to December 31, 2009, for both the spliced ABX index and the ABX 06-1 vintage. Because the ABX 06-2 vintage was not issued until July 19, 2006, the data set is unbalanced as the sample period runs from July 19, 2006, to December 31, 2009, for this vintage.

4.3.1. Longstaff (2010) Spliced ABX Index

Longstaff (2010) constructs an on-the-run ABX index by splicing the series together at the date that each new vintage is issued. The series is therefore spliced together on 19 July 2006, 19 January 2007 and 19 July 2007, respectively. As each new series began trading at par it is necessary to re-base the series at each splicing date.

The sample is divided into three separate one-year periods, the 2006 "pre-crisis" period, the 2007 "subprime-crisis" period and the 2008 "global-crisis" period, to test for contagion when moving from tranquil "normal" market conditions to a volatile crisis period. We extend the original sample to include 2009 as a "post-crisis" period.

4.4. Preliminary Analysis

Figures 4.1, 4.2 and 4.3 plot the time series of ABX weekly returns for each of the ABX data sets analysed for the entire sample period.

[**Insert Figures 4.1 - 4.3 about here**]

[5] The ABX 07-1 and 07-2 vintages are not analysed due to the fact that they were both issued in the volatile period of 2007 and so do not provide a tranquil non-crisis period with which to compare results.

These illustrate that during the 2006 "normal" period all five ABX assets were stable in each ABX series analysed. From 2007 onwards, however, returns in all three indexes become increasingly volatile as the crisis hit. This volatility continues throughout 2008 and 2009, although it does diminish somewhat. However, returns do not revert to the stable values experienced during 2006, suggesting that this market was still subject to volatility during the "post-crisis" period.

[**Insert Tables 4.1 - 4.3 about here**]

Tables 4.1, 4.2 and 4.3 report summary statistics for weekly percentage returns for the three ABX data sets examined in each of the four years in the sample period. The results suggest that normality is rejected in all cases, evidenced by excess kurtosis and negative skewness in almost all cases. In 2006 the two highest ratings in the spliced ABX index experience positive mean returns, reflecting this relatively stable period. All mean returns are positive for the ABX 06-1 vintage during 2006, contrasting with the ABX 06-2 vintage, in which all assets are mean negative. These differences are probably driven by the differing quality of the assets underlying the two traded vintages as the deals included in the ABX 06-1 vintage would have been originated in the second half of 2005 and so would be of considerably better quality than those included in the ABX 06-2 vintage. The descriptive statistics for 2007 reflect the volatile period entered into during that year. Mean returns are negative in all cases and are monotonically related to credit rating, indicating that the lower-rated assets were hit hardest during the subprime crisis. Unsurprisingly volatility of returns is considerably higher in 2007, 2008 and 2009 relative to 2006 but is not inversely related to credit rating as it suggests that the middle A-rated is the most volatile asset in both the spliced ABX index and the ABX 06-2 vintage while the BBB-rated asset is the most volatile in the

ABX 06-1 vintage. The effect of the crisis is also evidenced by the widening of the gap between minimum and maximum values relative to 2006 with the absolute minimum values exceeding the corresponding maximum values in all cases. The increase in the size of this gap indicates that the magnitudes of returns were fluctuating more during the crisis period.

Turning to 2008 mean returns become increasingly negative and standard deviations remain high, suggesting that the global credit crunch negatively affected ABX returns even more so than the subprime shock.

Summary statistics for the "post-crisis" period of 2009 exhibit some evidence of recovery as markets rebounded with some positive mean returns and declines in volatility.

Overall, these descriptive statistics illustrate the effect of the subprime and global crises on the ABX evidenced by falling mean returns and higher standard deviations. The next step is to analyse if this higher volatility led to an increase in linkages between these assets. As a preliminary examination of how the relationship between ABX tranches may have changed over the sample period Tables 4.4, 4.5 and 4.6 report raw correlations for weekly percentage returns of the three ABX data sets examined for each of the four years in the sample period.

[**Insert Tables 4.4 - 4.6 about here**]

The average correlation among ABX assets increases considerably between 2006 and 2007, indicating that during the "subprime-crisis" period these assets were subject to higher degrees of co-movement, consistent with the assets experiencing a common shock. This then decreases during the subsequent "global-crisis" and "post-crisis" periods, suggesting that linkages between these assets were strongest during the subprime crisis. In order to further examine how the correlation among these assets may have changed over time rolling correlations are calculated using a window width of 24. This window width is chosen due to the relatively short data range and also as the ABX 06-2 vintage was issued six months after the ABX 06-1 vintage. Alternative window widths are also employed and our conclusions do not change.

[**Insert Figures 4.4 - 4.6 about here**]

Figures 4.4, 4.5 and 4.6 indicate that these experienced different relationships during the sample period, and also that the relationships between the ratings tranches differed across the three ABX series examined. For the traded assets this again suggests that the vintages should be treated as separate entities and it also highlights differences between the spliced ABX index and those ABX vintages that investors were actually purchasing in the market. For example, the correlation between the two highest-rated assets in the spliced ABX index increases during 2007, as the crisis hit, and then declines during 2008 before settling close to its pre-crisis pattern. However, the correlation between the similarly rated assets in the ABX 06-1 vintage, while also increasing with the onset of 2007, remained relatively high throughout 2008 and 2009 and does not revert to its pre-crisis level. Comparing these with correlations between the AAA- and AA-rated assets in the ABX 06-2 vintage we see an initial high correlation that remains until mid-2008 before falling substantially. These differences could be due to the higher quality of the underlying assets in the ABX 06-1 vintage causing the two higher ratings to behave similarly during crisis periods, while those comprising the ABX 06-2 vintage were of lower quality and so the two highest ratings tranches became increasingly heterogeneous over the volatile sample period. Overall these results again indicate that these assets became increasingly interrelated once the subprime crisis hit in 2007. However, as Forbes & Rigobon (2002) prove, increased correlation does not necessarily constitute contagion. In order to examine the relationship between these assets we therefore employ the VAR framework presented by Longstaff (2010).

4.5. VAR 1 Analysis

In order to test for contagion within the ABX a five variable VAR is estimated on the ratings tranches of the three ABX data sets under analysis in line with Longstaff (2010). The VAR specification takes the form:

$$ABX_t = \alpha + \sum_{k=1}^{K} \beta_k ABX_{t-k} + \epsilon_t, \tag{4.1}$$

in which ABX_t denotes the ABX asset rating return that appears as the dependent variable while ABX denotes the ABX asset ratings tranche returns whose lagged values appear as explanatory variables. K denotes lag length, which is four weeks for the spliced ABX index and ABX 06-1 vintage and two weeks for the ABX 06-2 vintage, as suggested by the Akaike Information Criterion. The VAR system is estimated individually for each of the five different ratings classes and for each of the three ABX series considered.

In Longstaff (2010) the original application is characterized by a “normal” period in which the ABX assets behave independently from the other assets considered. This is unlikely to be true analysing the ABX vintages in isolation since the assets are interrelated in the pool structure. As our definition of contagion requires an increase in co-movement in excess of that experienced in non-crisis times we must first establish the interdependencies of the assets by examining the VAR results for 2006 only.

4.5.1. VAR 1 Results

Tables 4.7, 4.8 and 4.9 provide results for the VAR estimation performed on the three ABX indexes for 2006. Reported are the Newey-West adjusted t-statistics for the individual coefficients estimated, as the residuals are likely to have a non-constant variance, along with the p-values of the F-test that $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$. This is a test of the hypothesis that ABX asset returns in one ratings class Granger-cause subsequent returns in other ratings classes. Also reported are the R^2s for each VAR estimated.

[**Insert Tables 4.7 - 4.9 about here**]

It is clear that the ABX assets included in all three analyses were subject to varying degrees of interdependencies during 2006. In the spliced ABX index the highest-rated tranche returns Granger-cause returns in every other asset class and are, in turn, significantly impacted by every other asset class. One possible reason for this could be that this tranche would have dominated the CDO structure which could have led to it significantly impacting all other tranches. The lower two asset classes are significantly affected only by the highest-rated asset and, in the case of the BBB- rating, by the middle A-rated tranche. In turn, these asset returns have a significant effect upon only the AAA-rated asset, and the BBB- has a marginal significant effect upon the A-rated asset. This may be due to the fact that during this tranquil period these lower-rated assets would have been the least liquid within the CDO and so they may not have had much of an impact upon the rest of the index. Turning to the individual t-statistics we see that many of the higher-rated assets have significant predictive ability of up to four weeks ahead during 2006, suggesting price discovery existed during this “normal” period. The R^2's for the VARs decline considerably as the credit rating of the dependent variable employed decreases, suggesting that the higher-rated assets have more power when it comes to explaining variation in the ABX data.

The VAR estimation results for the ABX 06-1 vintage show greater evidence of interdependencies during the 2006 tranquil period when compared to those for the spliced ABX index. Returns in all ratings tranches are Granger-caused by almost all other ratings classes, with few exceptions.

The VAR estimation results for the ABX 06-2 vintage suggest that there are lower levels of interdependencies among the ABX assets in this vintage than in the previous ABX 06-1 vintage and the spliced ABX index. The two highest-rated assets are significantly affected by almost every other ratings tranche in the vintage. As reported earlier these two tranches were highly correlated during this period so it is possible they would have been impacted by other tranches in a similar fashion. The lower three tranches are relatively unaffected, and for the most part behave independently of each other during this "normal" market period. Again, this could be due to the illiquid nature of these riskier tranches. The fact that this later issued vintage displays less evidence of interdependencies among ratings than the earlier issuance could be due to differing risk profiles among vintages along with higher volatility and lesser degrees of co-movement among assets, as reported in section 4.4.

Altogether, these results emphasize that the assets comprising the two traded ABX vintages behaved differently, even in "normal" periods. The results also highlight the differences between the spliced ABX index and those traded in the market. In terms of testing for contagion, the existence of interdependencies among assets in the "normal" period of 2006 implies that we cannot use the VAR framework as presented by Longstaff (2010) to test for significant changes in the relationships between these assets in the crisis periods of 2007 and 2008 and so a modified version must be employed.

4.6. VAR 2 Analysis

Many tests for the presence of contagion employ dummy variables to account for a change in regime, such as Forbes & Rigobon (2002), Favero & Giavazzi (2002) and Bae et al. (2003).[6] This is the approach taken here. We define three dummy variables. To account for the "subprime-crisis" period of 2007 a dummy variable, $D1$, is included, taking a value of one during 2007 and zero otherwise. To account for the "global-crisis" period of 2008 a dummy variable, $D2$, is included, taking a value of one during 2008 and zero otherwise. To account for the "post-crisis" period of 2009 a dummy variable, $D3$, is included, taking a value of one during 2009 and zero otherwise. The dummy variables are thus defined as:

$$D1 = \begin{cases} 0 \text{ if } 2006 \\ 1 \text{ if } 2007 \\ 0 \text{ if } 2008 \\ 0 \text{ if } 2009 \end{cases}, \quad D2 = \begin{cases} 0 \text{ if } 2006 \\ 0 \text{ if } 2007 \\ 1 \text{ if } 2008 \\ 0 \text{ if } 2009 \end{cases}, \quad D3 = \begin{cases} 0 \text{ if } 2006 \\ 0 \text{ if } 2007 \\ 0 \text{ if } 2008 \\ 1 \text{ if } 2009 \end{cases}.$$

These dummy variables are then included in the following model:

$$ABX_t = \alpha_0 + \sum_{k=1}^{K} \alpha_k ABX_{t-k} + \beta_0 D1 + \sum_{k=1}^{K} D1(\alpha_k - \beta_k) ABX_{t-k},$$
$$+\delta_0 D2 + \sum_{k=1}^{K} D2(\alpha_k - \delta_k) ABX_{t-k} + \gamma_0 D3 + \sum_{k=1}^{K} D3(\alpha_k - \gamma_k) ABX_{t-k} + \epsilon_t, \qquad (4.2)$$

[6] For a detailed discussion and comparison of these and other tests for contagion please see Dungey et al. (2005).

in which α_0 denotes the 2006 constant term, $\beta_0 D1$ denotes the 2007 constant term, $\delta_0 D2$ denotes the 2008 constant term, $\gamma_0 D3$ denotes the 2009 constant term, ABX_t denotes the ABX ratings tranche included as a dependent variable and K denotes lag length which, as before, is four weeks for the spliced ABX index and the ABX 06-1 vintage and two weeks for the ABX 06-2 vintage, as determined by the Akaike Information Criterion.

In this study dummy variables are included to test for contagion by testing for stability of regression coefficients. They are used to test the hypothesis that the crisis periods examined have a significant impact on the coefficients. If the estimated coefficients on the dummy variables are statistically significant this would indicate the presence of contagion. The inclusion of dummy variables enables us to test whether the relationships between assets during 2007, 2008 and 2009 are significantly different than during the "normal" period of 2006. Therefore, if we observe no change then we conclude that the assets are subject only to "normal" market interdependencies.

4.6.1. VAR 2 Results

Table 4.10 provides the VAR estimation results for each of the three ABX series analysed. Reported are the p-values of the F-tests that the indicated coefficients are jointly zero.

[**Insert Table 4.10 about here**]

The results for 2007 indicate evidence of contagion within the ABX during 2007 and that this contagion mainly affected the three higher-rated assets. As all tranches are significantly affected to some degree this suggests that the ABX assets were hit by a common shock, which is reasonable based on the documented evolution of the crisis. During 2007 this common shock was the bursting of the property bubble and the subsequent collapse of the real estate market, leading to mass mortgage defaults and thus to investors reassessing the risk of mortgage-backed securities. In both the spliced ABX index and the ABX 06-2 vintage the AAA-rated asset significantly impacts all other ratings tranches and is also significantly affected by all other asset classes, as are the AA- and A-rated tranches. There are several possible reasons for the consistent significant effect of the AAA-rated asset. Firstly, this tranche accounts for over 80% of the CDO structure and so dominates the ABX indexes. Secondly, this tranche would have been the most popular with investors prior to the crisis due to the misconception that it was equivalent to a AAA-rated corporate bond and so it would have been the most liquid ABX asset. This tranche would have continued to be the most liquid in the indexes even during the volatile "subprime crisis" period as many of the assets underlying the lower-rated assets would have been wiped out by defaults and investors would have lost all confidence in these lowest ratings. Finally, as Coval et al. (2009) state, a common shock can effectively transfer risk from lower- to higher-rated tranches. The results for the ABX 06-2 vintage in 2007 also suggest that it was the higher-rated assets that were significantly affected.[7] There is more evidence of contagion in this traded vintage than in the spliced ABX index suggesting that the latter may not provide an accurate depiction of what was happening in this market during the sample

[7] As stated above a lag length of three or four weeks is not feasible in this ABX 06-2 vintage model. As an alternative to this the analysis was performed on daily data over the same period, however the shortage of data led to imprecise estimated coefficients. A possible reason for this could be that, as discussed by Armour et al.(1996), a shortcoming of using such high frequency data in a VAR is that this data can be quite noisy, causing larger standard errors and leading to less meaningful conclusions. Also, Silklos (1993) states that increasing frequency in order to increase sample size is not equivalent to using a longer sample and is insufficient when it comes to analysing long term relationships between variables. A lag length of two is employed, which must be kept in mind when comparing results to those obtained using a lag length of four weeks.

period. There is less evidence of contagion in the ABX 06-2 vintage than in both the spliced ABX index and the ABX 06-1 vintage, again highlighting differences among vintages.

Turning to the results for the "global-crisis" period of 2008 we see decreased evidence of contagion relative to 2007. This is likely due to the fact that the market for these securities came to almost a complete halt with the onset of the liquidity crisis in September 2008 as investors became increasingly unwilling to invest in these opaque products. The lack of trades effectively closed down the transmission channels for contagion. There is increased evidence of contagion in 2009, relative to 2008, probably due to the market rebounding following the credit crunch, leading to increases in trading volumes.

4.6.2. Analysing the Sum of Lagged Coefficients

To investigate the total impact of ABX tranche returns on other tranches over the sample period we analyse the sum of lagged coefficients from the VAR results discussed in the previous section. This sum can be seen as a measure of persistence of a shock to the process (Mikusheva, 2007) and allows us to ascertain if any contagious effects are short-lived or long-term in nature. Table 4.11 provides the sum of lagged coefficients for the three ABX indexes. Reported are the sum of the coefficients on the lagged terms of each variable, along with the p-values of the Wald test of the null hypothesis that the coefficients sum to zero.

[**Insert Table 4.11 about here**]

The two traded ABX vintages show evidence of persistent shocks emanating from the higher-rated assets, suggesting that these markets remained in a state of turmoil and did not quickly revert to a pre-crisis state following the shock. This is probably due to the lack of investor confidence causing them to stay out of the market, particularly during the autumn of 2008 as market wide reassessments of the risk of these products were still under way following the subprime crisis. The effect emanating from the higher-rated assets only is probably due to the reasons outlined above.

For the spliced ABX index, persistent shocks emanate from the lower-rated assets, a result in direct contrast to those presented for the two traded vintages. Therefore, any shocks emanating from the higher ratings were short-lived in nature, essentially "dying out" by the end of the sample period. The effect of splicing the data probably causes this result, as the riskier 07-2 traded vintage would have dominated this index.

4.7. Conclusions

The crisis of 2007 has been linked in no small part to the innovative U.S. subprime mortgage-backed securities market. The ABX.HE indexes, a basket of these securities, were followed closely by investors and financial institutions as a barometer of subprime mortgage market conditions in the years preceding the crisis, yet no published literature examines whether the ABX indexes were subject to contagion during the 2007 crisis. The seminal work that tests explicitly for contagion from the ABX, Longstaff (2010), provides the basis for this study. Employing the spliced ABX index and VAR framework presented by Longstaff (2010) we test for contagion within the ABX to try to uncover a driving force within the indexes. An initial analysis of the ABX during

2006 suggests that interdependencies between assets existed during this "normal" market period and so dummy variables are included in the VAR framework to account for crisis periods and test for contagion.

The results provide evidence of contagion following the onset of the crisis. During the 2007 subprime crisis there is evidence of contagion among the higher-rated assets in the ABX. Once the "global-crisis" period of 2008 hits, the predictive power of lagged ABX returns decreases. However, during 2009 evidence of Granger-causality increases within the ABX, perhaps due to a resumption of trades in the ABX following the 2008 credit crunch.

It is clear that the market turmoil was widespread with increased sensitivities across all assets. It is not possible to identify one consistent driver of the system of assets. At best, we have shown that the higher-rated assets were the source of more persistent shocks with price changes in lower-rated assets mostly associated with short-lived noise. Furthermore, we find important differences between asset interactions in the actual-traded assets and those in the constructed index. The latter tends to overweight the final, and thus most risky, vintage of asset and consequently displays different patterns of contagion.

Figure 4.1: Spliced ABX Index Weekly Returns.

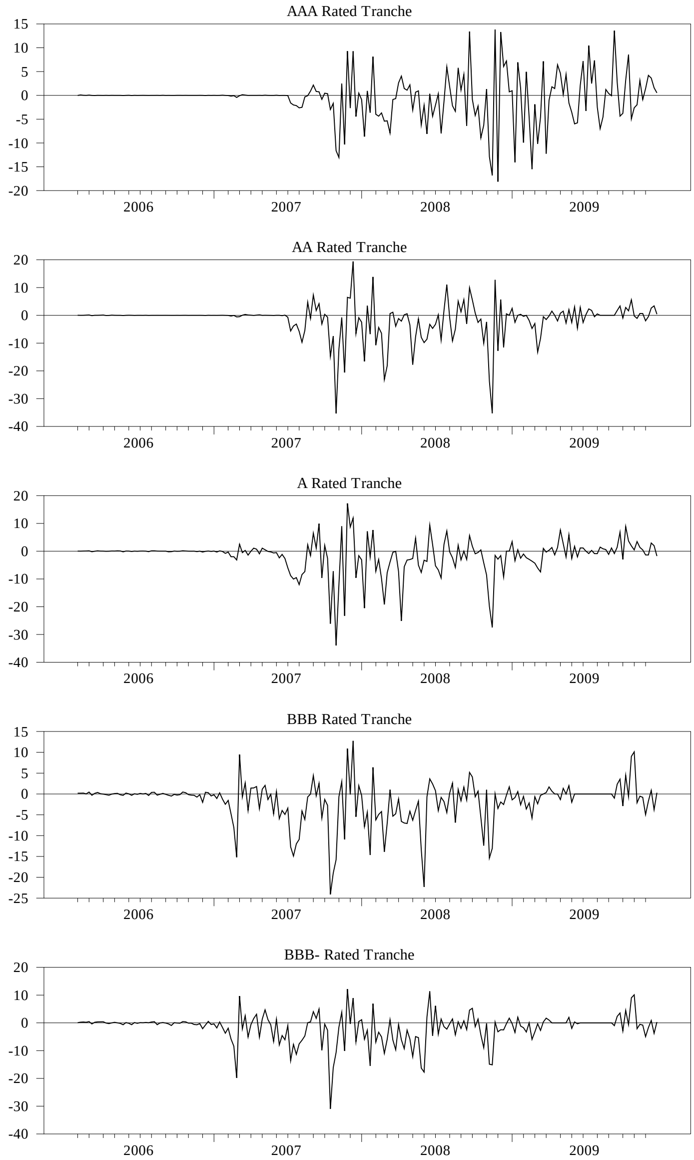


Figure 4.2: ABX 06-1 Vintage Weekly Returns.

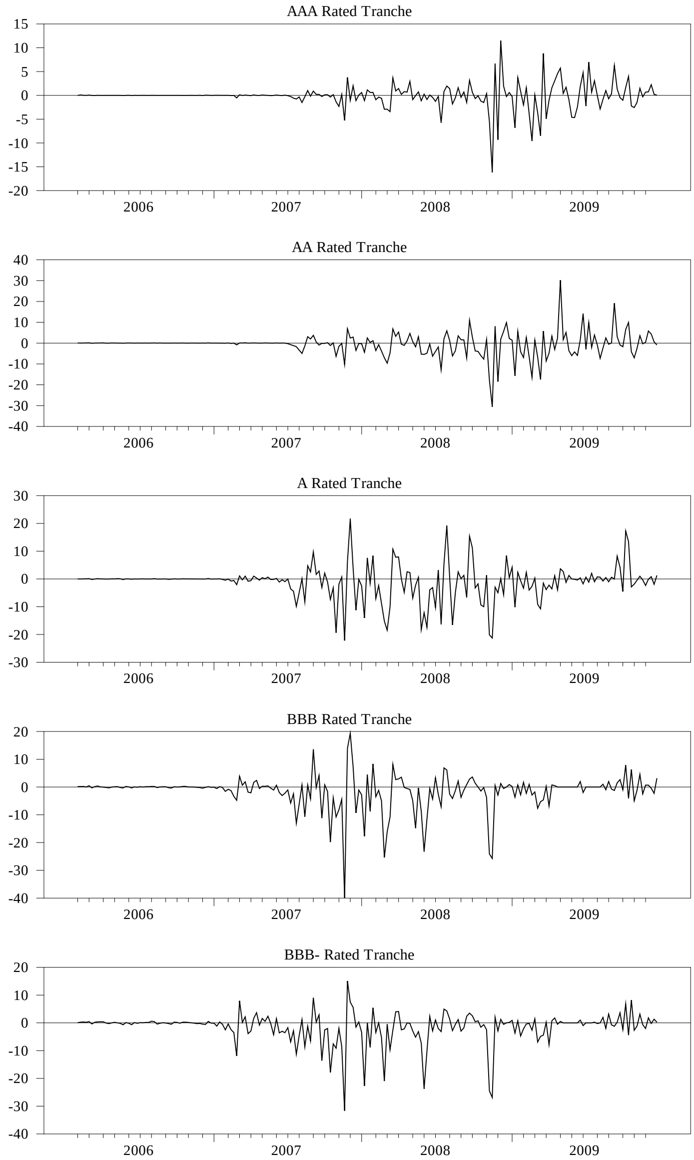


Figure 4.3: ABX 06-2 Vintage Weekly Returns.

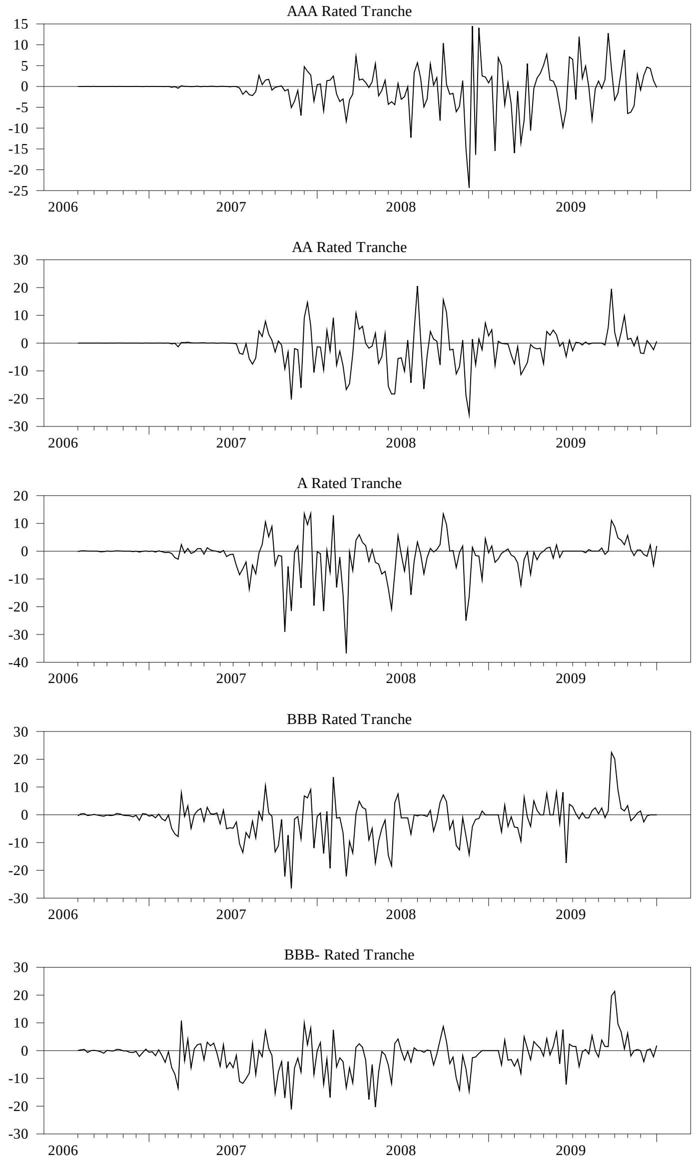


Figure 4.4: Spliced ABX Index Tranche Rolling Correlation Coefficients.
Window width = 24. This Figure illustrates rolling correlations between the indicated ABX asset weekly percentage returns. The header above each panel indicates the two ABX assets whose rolling correlations are illustrated.

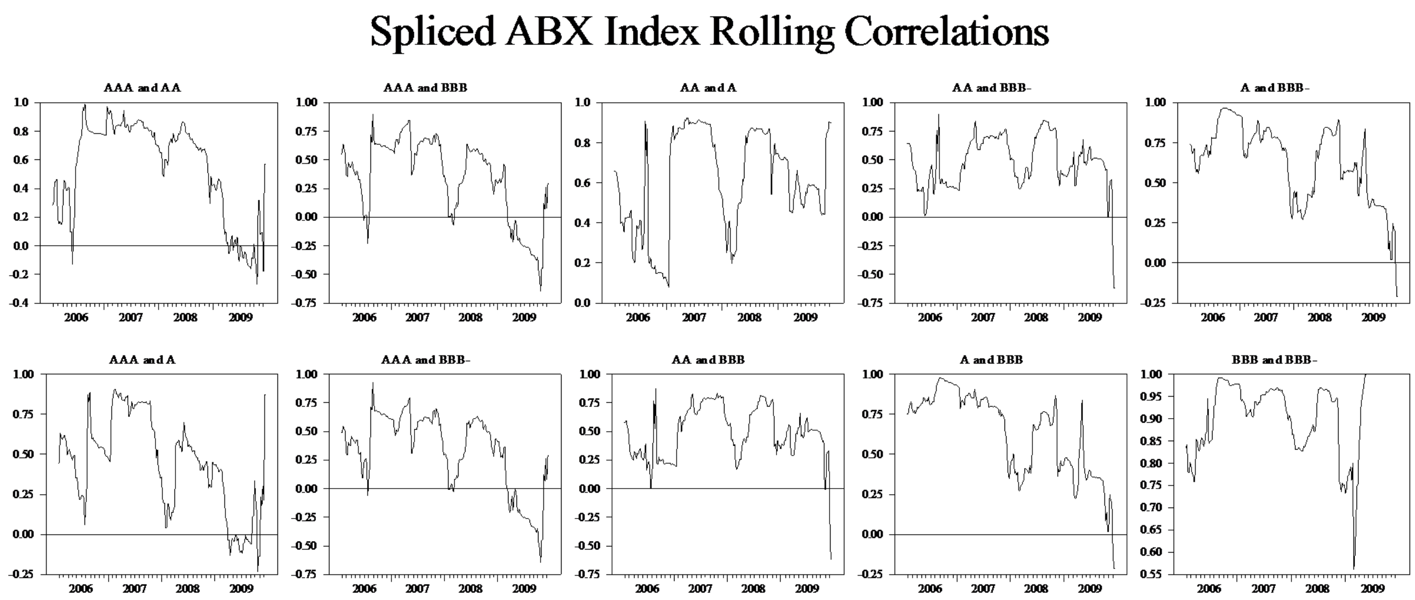


Figure 4.5: ABX 06-1 Vintage Tranche Rolling Correlation Coefficients.
Window width = 24. This Figure illustrates rolling correlations between the indicated ABX asset weekly percentage returns. The header above each panel indicates the two ABX assets whose rolling correlations are illustrated.

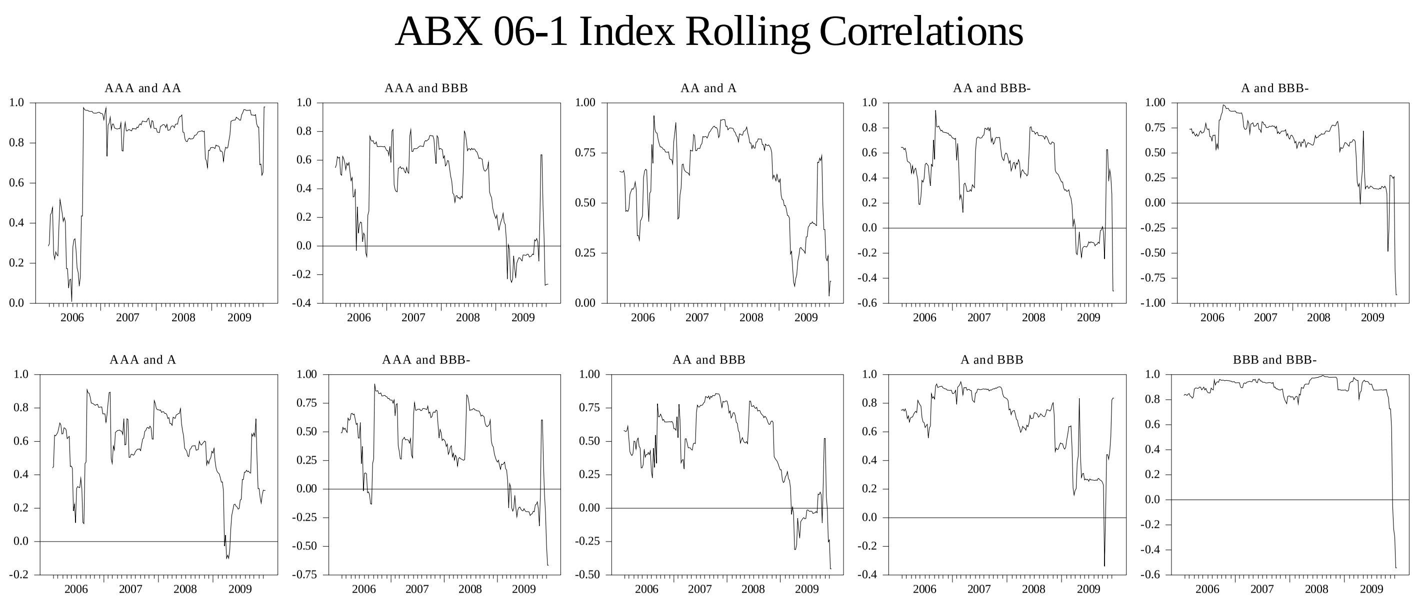


Figure 4.6: ABX 06-2 Vintage Tranche Rolling Correlation Coefficients.
Window width = 24. This Figure illustrates rolling correlations between the indicated ABX asset weekly percentage returns. The header above each panel indicates the two ABX assets whose rolling correlations are illustrated.

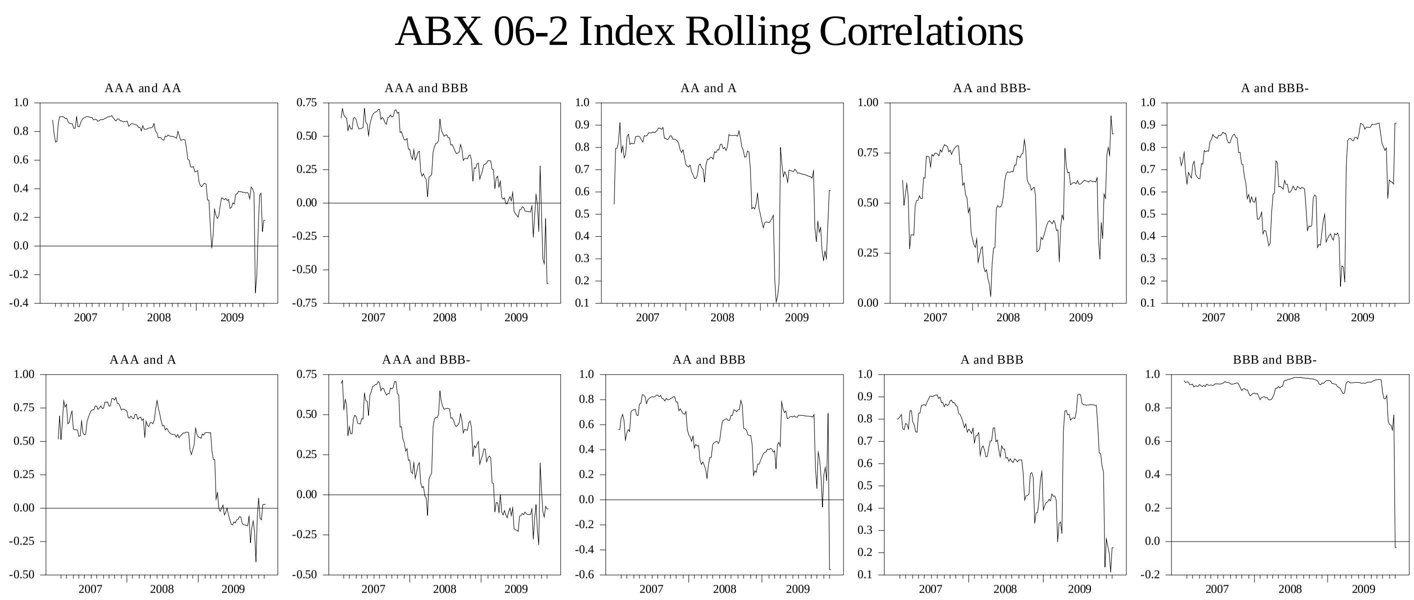


Table 4.1: Summary Statistics For Spliced ABX Index Weekly Percentage Returns

Notes: This table reports summary statistics for the weekly percentage returns for the spliced ABX index for the indicated year. Std. Dev. denotes standard deviation; Min. denotes minimum; Max. denotes maximum. The sample runs from January 19, 2006 to December 31, 2009.

Year	Rating	Mean	Std.Dev.	Skewness	Kurtosis	Min.	Max.
2006	AAA	0.002	0.022	2.145	8.699	-0.045	0.090
	AA	0.008	0.042	0.361	3.171	-0.119	0.130
	A	-0.012	0.100	-1.000	0.918	-0.301	0.140
	BBB	-0.067	0.393	-2.443	10.945	-1.979	0.465
	BBB-	-0.087	0.462	-1.834	5.692	-2.081	0.535
2007	AAA	-0.551	3.465	-1.025	6.116	-12.230	9.737
	AA	-1.447	6.867	-1.940	9.411	-29.754	21.416
	A	-2.229	8.077	-1.338	4.036	-28.787	18.774
	BBB	-2.779	6.666	-0.764	1.717	-21.429	13.595
	BBB-	-2.840	6.824	-1.173	3.393	-26.618	12.940
2008	AAA	-1.016	6.443	0.004	0.938	-16.573	14.839
	AA	-3.499	8.527	-0.885	1.967	-29.697	14.838
	A	-3.544	6.996	-1.216	2.168	-23.980	9.845
	BBB	-3.407	5.373	-0.995	1.294	-20.000	6.594
	BBB-	-3.203	5.792	-0.379	0.403	-16.238	12.030
2009	AAA	-0.242	5.999	-0.367	0.368	-15.494	13.593
	AA	-0.262	2.987	-1.887	6.697	-13.239	5.576
	A	0.226	3.102	0.417	1.190	-7.459	8.883
	BBB	-0.094	2.661	1.642	5.843	-5.789	10.104
	BBB-	-0.094	2.714	1.497	5.277	-5.948	10.104

Table 4.2: Summary Statistics For ABX 06-1 Vintage Weekly Percentage Returns

Notes: This table reports summary statistics for the weekly percentage returns for the ABX 06-1 vintage for the indicated year. Std. Dev. denotes standard deviation; Min. denotes minimum; Max. denotes maximum. The sample runs from January 19, 2006 to December 31, 2009.

Year	Rating	Mean	Std.Dev.	Skewness	Kurtosis	Min.	Max.
2006	AAA	0.002	0.021	1.936	6.610	-0.030	0.090
	AA	0.012	0.043	0.273	1.706	-0.110	0.130
	A	0.005	0.073	-0.947	2.400	-0.229	0.150
	BBB	0.008	0.196	-0.289	-0.294	-0.408	0.457
	BBB-	0.011	0.310	-0.395	-0.340	-0.681	0.594
2007	AAA	-0.135	1.091	-1.253	12.187	-5.275	3.779
	AA	-0.321	2.384	-1.219	7.013	-10.233	6.889
	A	-0.931	6.145	-0.429	6.440	-22.199	21.685
	BBB	-2.056	8.288	-1.609	8.730	-39.969	19.365
	BBB-	-2.334	7.033	-1.344	5.567	-31.649	15.069
2008	AAA	-0.294	3.624	-1.231	8.637	-16.173	11.520
	AA	-1.809	7.186	-1.483	4.306	-30.580	10.949
	A	-3.123	9.251	0.020	-0.265	-21.270	19.165
	BBB	-3.442	8.227	-1.349	1.454	-25.726	8.319
	BBB-	-3.183	7.536	-1.941	3.361	-26.890	5.422
2009	AAA	0.030	3.608	-0.219	0.801	-9.590	8.812
	AA	0.019	8.001	0.934	3.658	-17.493	30.176
	A	-0.151	4.563	1.149	5.084	-10.756	17.258
	BBB	-0.416	2.813	0.064	1.750	-7.640	7.911
	BBB-	-0.364	2.814	0.097	2.192	-7.886	8.205

Table 4.3: Summary Statistics For ABX 06-2 Vintage Weekly Percentage Returns

Notes: This table reports summary statistics for the weekly percentage returns for the ABX 06-2 vintage for the indicated year. Std. Dev. denotes standard deviation; Min. denotes minimum; Max. denotes maximum. The sample runs from January 19, 2006 to December 31, 2009.

Year	Rating	Mean	Std.Dev.	Skewness	Kurtosis	Min.	Max.
2006	AAA	-0.0004	0.011	-0.648	1.462	-0.030	0.020
	AA	-0.001	0.014	-0.470	2.095	-0.040	0.030
	A	-0.032	0.111	-0.675	0.361	-0.301	0.140
	BBB	-0.170	0.519	-1.902	6.331	-2.000	0.464
	BBB-	-0.220	0.587	-1.478	3.591	-2.103	0.534
2007	AAA	-0.274	1.827	-0.820	4.480	-6.991	4.754
	AA	-0.903	5.320	-0.922	4.803	-20.328	14.643
	A	-1.758	7.562	-1.198	3.653	-29.020	13.527
	BBB	-2.981	6.892	-1.032	2.427	-26.474	10.451
	BBB-	-3.100	6.500	-0.347	0.509	-21.164	10.782
2008	AAA	-1.062	6.606	-0.759	3.031	-24.349	14.495
	AA	-3.056	9.258	-0.067	0.171	-25.764	20.556
	A	-3.821	9.210	-1.176	2.448	-36.741	13.423
	BBB	-3.620	7.397	-0.554	0.160	-22.155	13.562
	BBB-	-3.482	6.287	-0.810	0.404	-20.303	8.684
2009	AAA	-0.164	6.336	-0.539	0.311	-15.992	12.789
	AA	-0.261	4.780	1.062	5.321	-11.340	19.535
	A	-0.156	3.519	-0.020	4.199	-12.157	11.077
	BBB	0.982	5.951	0.996	5.449	-17.327	22.452
	BBB-	0.978	5.639	1.371	4.493	-12.215	21.357

Table 4.4: Spliced ABX Index Correlation Coefficients

Notes: This table reports raw correlation coefficients for the weekly percentage returns for the spliced ABX index for the indicated year. The sample runs from January 19, 2006 to December 31, 2009

2006

Average Correlation: 0.50

Rating	AAA	AA	A	BBB	BBB-
AAA	1.00				
AA	0.44	1.00			
A	0.36	0.50	1.00		
BBB	0.23	0.32	0.77	1.00	
BBB-	0.33	0.44	0.76	0.85	1.00

2007

Average Correlation: 0.74

Rating	AAA	AA	A	BBB	BBB-
AAA	1.00				
AA	0.85	1.00			
A	0.80	0.89	1.00		
BBB	0.58	0.69	0.80	1.00	
BBB-	0.51	0.60	0.77	0.95	1.00

2008

Average Correlation: 0.59

Rating	AAA	AA	A	BBB	BBB-
AAA	1.00				
AA	0.75	1.00			
A	0.44	0.69	1.00		
BBB	0.44	0.62	0.53	1.00	
BBB-	0.39	0.59	0.52	0.90	1.00

2009

Average Correlation: 0.40

Rating	AAA	AA	A	BBB	BBB-
AAA	1.00				
AA	0.36	1.00			
A	0.29	0.69	1.00		
BBB	0.04	0.38	0.39	1.00	
BBB-	0.09	0.39	0.45	0.94	1.00

Table 4.5: ABX 06-1 Vintage Correlation Coefficients

Notes: This table reports raw correlation coefficients for the weekly percentage returns for the ABX 06-1 vintage for the indicated year. The sample runs from January 19, 2006 to December 31, 2009

2006

Average Correlation: 0.55

Rating	AAA	AA	A	BBB	BBB-
AAA	1.00				
AA	0.32	1.00			
A	0.41	0.65	1.00		
BBB	0.42	0.51	0.71	1.00	
BBB-	0.35	0.56	0.70	0.84	1.00

2007

Average Correlation: 0.77

Rating	AAA	AA	A	BBB	BBB-
AAA	1.00				
AA	0.87	1.00			
A	0.58	0.81	1.00		
BBB	0.72	0.78	0.88	1.00	
BBB-	0.68	0.69	0.74	0.93	1.00

2008

Average Correlation: 0.70

Rating	AAA	AA	A	BBB	BBB-
AAA	1.00				
AA	0.84	1.00			
A	0.55	0.79	1.00		
BBB	0.54	0.68	0.78	1.00	
BBB-	0.52	0.64	0.70	0.92	1.00

2009

Average Correlation: 0.42

Rating	AAA	AA	A	BBB	BBB-
AAA	1.00				
AA	0.85	1.00			
A	0.42	0.48	1.00		
BBB	0.14	0.20	0.44	1.00	
BBB-	0.13	0.22	0.41	0.86	1.00

Table 4.6: ABX 06-2 Vintage Correlation Coefficients

Notes: This table reports raw correlation coefficients for the weekly percentage returns for the ABX 06-2 vintage for the indicated year. The sample runs from July 19, 2006 to December 31, 2009.

2006

Average Correlation: 0.48

Rating	AAA	AA	A	BBB	BBB-
AAA	1.00				
AA	0.69	1.00			
A	0.24	0.43	1.00		
BBB	0.03	0.21	0.83	1.00	
BBB-	0.26	0.44	0.80	0.86	1.00

2007

Average Correlation: 0.77

Rating	AAA	AA	A	BBB	BBB-
AAA	1.00				
AA	0.91	1.00			
A	0.72	0.86	1.00		
BBB	0.63	0.76	0.86	1.00	
BBB-	0.59	0.65	0.76	0.95	1.00

2008

Average Correlation: 0.63

Rating	AAA	AA	A	BBB	BBB-
AAA	1.00				
AA	0.76	1.00			
A	0.56	0.77	1.00		
BBB	0.38	0.59	0.75	1.00	
BBB-	0.37	0.53	0.65	0.92	1.00

2009

Average Correlation: 0.50

Rating	AAA	AA	A	BBB	BBB-
AAA	1.00				
AA	0.46	1.00			
A	0.33	0.65	1.00		
BBB	0.15	0.53	0.65	1.00	
BBB-	0.07	0.53	0.68	0.95	1.00

Table 4.7: Spliced ABX Index 2006 VAR 1 Estimation Results

Notes: This table reports results for the following VAR equation:

$$ABX_t = \alpha + \sum_{k=1}^{4} \beta_k ABX_{t-k} + \epsilon_t,$$

in which ABX_t denotes the ABX asset rating weekly percentage return that appears as the dependent variable while ABX denotes the ratings tranche weekly percentage returns whose lagged values appear as explanatory variables. Four lags are suggested by the Akaike Information Criterion. The sample runs from January 19, 2006 to December 31, 2009. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Y	ABX	R^2	β_1	β_2	β_3	β_4	p
AAA	AAA	0.70	-3.96^{**}	2.27^{**}	3.82^{**}	0.49	0.00^{**}
	AA		-0.69	-3.12^{**}	-2.42^{**}	-1.74^{*}	0.00^{**}
	A		2.04^{**}	0.16	0.65	-4.90^{**}	0.00^{**}
	BBB		-1.39	-2.70^{**}	-1.58	2.87^{**}	0.00^{**}
	BBB-		1.98^{*}	0.86	1.26	-1.49	0.00^{**}
AA	AAA	0.46	-0.63	2.83^{**}	1.51	-0.41	0.00^{**}
	AA		-3.41^{**}	-3.61^{**}	-2.04^{**}	-1.93^{*}	0.00^{**}
	A		0.37	-1.42	-1.69^{*}	-1.07	0.33
	BBB		0.41	0.17	0.28	0.78	0.86
	BBB-		0.86	0.77	0.38	1.28	0.55
A	AAA	0.41	-2.45^{**}	-0.22	3.02^{**}	0.60	0.00^{**}
	AA		-3.08^{**}	1.99^{*}	-2.19^{**}	-1.89^{*}	0.00^{**}
	A		0.56	-1.51	0.15	-1.56	0.00^{**}
	BBB		-0.27	-1.24	-1.57	0.73	0.50
	BBB-		0.79	2.40^{**}	1.02	0.31	0.06^{*}
BBB	AAA	0.24	-1.85^{*}	0.01	3.30^{**}	1.45	0.00^{**}
	AA		-0.81	-1.83^{*}	-0.75	-0.61	0.42
	A		-0.11	0.09	-0.31	-0.74	0.43
	BBB		0.21	-0.27	-0.75	0.99	0.84
	BBB-		-0.08	1.04	0.78	-0.91	0.58
BBB-	AAA	0.39	-2.41^{**}	0.65	1.65	1.63	0.00^{**}
	AA		-1.50	-1.19	-1.54	0.12	0.27
	A		0.12	-0.86	0.05	-3.05^{**}	0.00^{**}
	BBB		0.42	0.25	-0.10	1.14	0.80
	BBB-		0.53	0.78	0.32	-0.31	0.61

Table 4.8: ABX 06-1 Vintage 2006 VAR 1 Estimation Results

Notes: This table reports results for the following VAR equation:

$$ABX_t = \alpha + \sum_{k=1}^{4} \beta_k ABX_{t-k} + \epsilon_t,$$

in which ABX_t denotes the ABX asset rating weekly percentage return that appears as the dependent variable while ABX denotes the ratings tranche weekly percentage returns whose lagged values appear as explanatory variables. Four lags are suggested by the Akaike Information Criterion. The sample runs from January 19, 2006 to December 31, 2009. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Y	ABX	R^2	β_1	β_2	β_3	β_4	p
AAA	AAA	0.61	-2.23^{**}	-1.29	7.30^{**}	0.06	0.00^{**}
	AA		2.75^{**}	-1.92^{*}	-0.13	-2.63^{**}	0.00^{**}
	A		-0.30	0.20	1.33	0.20	0.63
	BBB		-0.91	-0.53	-2.81^{**}	1.82^{*}	0.01^{**}
	BBB-		-0.25	1.89^{*}	0.45	-2.51^{**}	0.08^{*}
AA	AAA	0.58	1.66^{*}	-1.09	4.98^{**}	-1.00	0.00^{**}
	AA		0.27	-4.51^{**}	-0.79	-3.40^{**}	0.00^{**}
	A		-2.66^{**}	-1.50	-1.44	0.20	0.00^{**}
	BBB		-1.54	1.81^{*}	-4.36^{**}	0.41	0.00^{**}
	BBB-		0.82	0.41	2.91^{**}	0.37	0.00^{**}
A	AAA	0.53	-0.51	0.40	3.21^{**}	-0.82	0.08^{**}
	AA		-1.26	2.94^{**}	-1.58	-2.49^{**}	0.00^{**}
	A		-1.27	-1.78^{*}	0.69	-0.21	0.01^{**}
	BBB		0.69	-0.87	-1.83^{**}	-0.85	0.01^{**}
	BBB-		0.37	2.39^{**}	1.05	1.49	0.00^{**}
BBB	AAA	0.56	-1.97^{*}	2.01^{**}	5.18^{**}	0.14	0.00^{**}
	AA		-0.45	-2.85^{**}	-1.25	-1.05	0.01^{**}
	A		-1.83^{*}	-0.48	0.50	-0.34	0.00^{**}
	BBB		2.68^{**}	-0.22	-1.99^{*}	-0.15	0.01^{**}
	BBB-		0.00	0.96	1.23	0.65	0.02^{**}
BBB-	AAA	0.38	-0.25	0.54	2.87^{**}	-0.15	0.01^{**}
	AA		-0.82	-1.76^{*}	-0.72	-0.85	0.14
	A		-1.44	-0.44	-1.27	-1.03	0.00^{**}
	BBB		1.70	-0.18	-1.08	0.34	0.27
	BBB-		0.51	0.35	1.66^{*}	0.52	0.00^{**}

Table 4.9: ABX 06-2 Vintage 2006 VAR 1 Estimation Results

Notes: This table reports results for the following VAR equation:

$$ABX_t = \alpha + \sum_{k=1}^{2} \beta_k ABX_{t-k} + \epsilon_t,$$

in which ABX_t denotes the ABX asset rating weekly percentage return that appears as the dependent variable while ABX denotes the ratings tranche weekly percentage returns whose lagged values appear as explanatory variables. Two lags are suggested by the Akaike Information Criterion. The sample runs from July 19, 2006 to December 31, 2009. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Y	ABX	R^2	β_1	β_2	p
AAA	AAA	0.81	-4.77^{**}	-1.04	0.00^{**}
	AA		-1.29	1.31	0.36
	A		1.44	2.48^{**}	0.00^{**}
	BBB		-3.86^{**}	-3.54^{**}	0.00^{**}
	BBB-		4.21^{**}	-0.05	0.00^{**}
AA	AAA	0.80	2.30^{**}	2.87^{**}	0.02^{**}
	AA		-7.20^{**}	-2.03^{**}	0.00^{**}
	A		-0.46	1.96^{*}	0.08^{*}
	BBB		2.53^{**}	-0.24	0.03^{**}
	BBB-		0.65	-1.74^{*}	0.16
A	AAA	0.49	1.53	0.73	0.30
	AA		-3.05^{**}	-1.64	0.01^{**}
	A		-0.02	0.59	0.83
	BBB		0.57	1.35	0.40
	BBB-		0.27	0.19	0.94
BBB	AAA	0.45	0.91	2.06^{**}	0.12
	AA		-2.16^{**}	-2.18^{**}	0.08^{*}
	A		-1.38	1.24	0.32
	BBB		0.82	1.29	0.40
	BBB-		0.34	0.06	0.94
BBB-	AAA	0.44	0.80	2.15^{**}	0.10
	AA		-1.81	-1.40	0.19
	A		-0.61	0.27	0.82
	BBB		2.08^{**}	1.44	0.09^{*}
	BBB-		-0.11	0.02	0.99

Table 4.10: VAR 2 Estimation Results

Notes: This table reports results for the following VAR equation:

$$ABX_t = \alpha_0 + \sum_{k=1}^{K} \alpha_k ABX_{t-k} + \beta_0 D1 + \sum_{k=1}^{K} D1(\alpha_k - \beta_k) ABX_{t-k},$$

$$+\delta_0 D2 + \sum_{k=1}^{K} D2(\alpha_k - \delta_k) ABX_{t-k} + \gamma_0 D3 + \sum_{k=1}^{K} D3(\alpha_k - \gamma_k) ABX_{t-k} + \epsilon_t, \quad (4.3)$$

in which $D1$ denotes a dummy variable for 2007, $D2$ denotes a dummy variable for 2008, $D3$ denotes a dummy variable for 2009, α_0 denotes the 2006 constant term, $\beta_0 D1$ denotes the 2007 constant term, $\delta_0 D2$ denotes the 2008 constant term, $\gamma_0 D3$ denotes the 2009 constant term, ABX_t denotes the ABX ratings tranche weekly percentage returns included as a dependent variable and K denotes lag length which, as before, is four weeks for the spliced ABX index and the ABX 06-1 vintage and two weeks for the ABX 06-2 vintage, as determined by the Akaike Information Criterion. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Spliced ABX index

Regressor	Dependent AAA	AA	A	BBB	BBB-
AAA_{2007}	0.00**	0.00**	0.00**	0.00**	0.00**
AA_{2007}	0.00**	0.00**	0.00**	0.32	0.34
A_{2007}	0.00**	0.00**	0.02**	0.83	0.05**
BBB_{2007}	0.00**	0.00**	0.00**	0.84	0.39
$BBB-_{2007}$	0.00**	0.00**	0.00**	0.92	0.61
AAA_{2008}	0.11	0.43	0.00**	0.00**	0.00**
AA_{2008}	0.13	0.04**	0.08**	0.38	0.25
A_{2008}	0.00**	0.08**	0.22	0.42	0.00**
BBB_{2008}	0.25	0.14	0.30	0.13	0.16
$BBB-_{2008}$	0.24	0.35	0.05**	0.50	0.85
AAA_{2009}	0.02**	0.01**	0.00**	0.00**	0.00**
AA_{2009}	0.03**	0.00**	0.00**	0.56	0.30
A_{2009}	0.68	0.01**	0.02**	0.09*	0.00**
BBB_{2009}	0.00**	0.00**	0.00**	0.83	0.34
$BBB-_{2009}$	0.00**	0.00**	0.00**	0.52	0.14

ABX 06-1 vintage

Regressor	Dependent AAA	AA	A	BBB	BBB-
AAA_{2007}	0.00**	0.00**	0.00**	0.00**	0.00**
AA_{2007}	0.00**	0.00**	0.00**	0.00**	0.00**
A_{2007}	0.00**	0.00**	0.00**	0.06**	0.32
BBB_{2007}	0.07*	0.01**	0.00**	0.01**	0.40
$BBB-_{2007}$	0.57	0.05**	0.42	0.32	0.41
AAA_{2008}	0.00**	0.00**	0.03**	0.00**	0.02**
AA_{2008}	0.00**	0.00**	0.02**	0.38	0.31
A_{2008}	0.02**	0.09*	0.59	0.00**	0.00**
BBB_{2008}	0.07*	0.67	0.19	0.29	0.69
$BBB-_{2008}$	0.61	0.91	0.78	0.20	0.14
AAA_{2009}	0.03**	0.67	0.14	0.00**	0.02**
AA_{2009}	0.00**	0.00**	0.00**	0.01**	0.15
A_{2009}	0.03**	0.09*	0.25	0.00**	0.00**
BBB_{2009}	0.04**	0.00**	0.00**	0.01**	0.30
$BBB-_{2009}$	0.04**	0.00**	0.00**	0.08*	0.22

ABX 06-2 vintage

Regressor	Dependent AAA	AA	A	BBB	BBB-
AAA_{2007}	0.01**	0.04**	0.05**	0.22	0.16
AA_{2007}	0.00**	0.00**	0.00**	0.09*	0.17
A_{2007}	0.00**	0.01**	0.48	0.36	0.87
BBB_{2007}	0.08*	0.00**	0.00**	0.25	0.45
$BBB-_{2007}$	0.18	0.00**	0.00**	0.16	0.27
AAA_{2008}	0.26	0.14	0.30	0.12	0.10
AA_{2008}	0.34	0.00**	0.01**	0.08*	0.18
A_{2008}	0.50	0.51	0.71	0.30	0.77
BBB_{2008}	0.97	0.99	0.47	0.11	0.02**
$BBB-_{2008}$	0.41	0.76	0.16	0.37	0.37
AAA_{2009}	0.00**	0.22	0.31	0.12	0.10
AA_{2009}	0.07*	0.00**	0.01**	0.07*	0.18
A_{2009}	0.87	0.76	0.76	0.27	0.87
BBB_{2009}	0.46	0.44	0.04**	0.10	0.11
$BBB-_{2009}$	0.21	0.43	0.07*	0.15	0.23

Table 4.11: Sum Of Lagged Coefficients

Notes: This table reports results from the Wald test that the indicated coefficients from the following VAR equation sum to zero:

$$ABX_t = \alpha_0 + \sum_{k=1}^{K} \alpha_k ABX_{t-k} + \beta_0 D1 + \sum_{k=1}^{K} D1(\alpha_k - \beta_k) ABX_{t-k},$$

$$+\delta_0 D2 + \sum_{k=1}^{K} D2(\alpha_k - \delta_k) ABX_{t-k} + \gamma_0 D3 + \sum_{k=1}^{K} D3(\alpha_k - \gamma_k) ABX_{t-k} + \epsilon_t,$$

in which $D1$ denotes a dummy variable for 2007, $D2$ denotes a dummy variable for 2008, $D3$ denotes a dummy variable for 2009, α_0 denotes the 2006 constant term, $\beta_0 D1$ denotes the 2007 constant term, $\delta_0 D2$ denotes the 2008 constant term, $\gamma_0 D3$ denotes the 2009 constant term, ABX_t denotes the ABX ratings tranche weekly percentage returns included as a dependent variable and K denotes lag length which, as before, is four weeks for the spliced ABX index and the ABX 06-1 vintage and two weeks for the ABX 06-2 vintage, as determined by the Akaike Information Criterion. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Spliced ABX index					
	Dependent				
Regressor	AAA	AA	A	BBB	BBB-
AAA	-2.75	-3.46	-0.01	-3.11	-4.31
p	0.00**	0.11	1.00	0.85	0.82
AA	2.89	4.37	7.14	10.17	11.32
p	0.00**	0.00**	0.00**	0.20	0.07*
A	-0.73	0.28	0.32	4.06	8.51
p	0.32	0.71	0.79	0.19	0.01**
BBB	14.35	6.80	7.54	-0.92	0.39
p	0.00**	0.00**	0.00**	0.73	0.88
BBB-	-13.84	-5.45	-6.00	0.43	-2.46
p	0.00**	0.01**	0.00**	0.84	0.27
ABX 06-1 vintage					
	Dependent				
Regressor	AAA	AA	A	BBB	BBB-
AAA	-2.72	-5.73	-18.31	-24.64	-28.69
p	0.01**	0.04**	0.02**	0.02**	0.04**
AA	0.87	1.96	9.39	17.87	20.05
p	0.10	0.15	0.00**	0.00**	0.00**
A	-0.23	0.87	1.45	2.95	7.94
p	0.56	0.35	0.28	0.15	0.01**
BBB	-0.22	0.18	1.82	-1.62	0.86
p	0.83	0.93	0.40	0.60	0.78
BBB-	1.28	3.83	-0.59	1.18	-1.61
p	0.30	0.11	0.72	0.60	0.48
ABX 06-2 vintage					
	Dependent				
Regressor	AAA	AA	A	BBB	BBB-
AAA	3.32	4.32	-7.67	-73.08	-65.28
p	0.00**	0.09*	0.53	0.10	0.08*
AA	-2.36	-1.12	28.07	172.11	145.45
p	0.00**	0.40	0.03**	0.03**	0.10
A	0.53	1.70	0.84	0.57	0.93
p	0.35	0.01**	0.49	0.86	0.81
BBB	-0.59	0.57	1.64	-0.67	-1.23
p	0.40	0.49	0.12	0.71	0.49
BBB-	0.97	-0.13	-0.02	0.08	0.21
p	0.18	0.88	0.28	0.96	0.90

Chapter 5

Analysing Contagion from the U.S. Subprime Mortgage-Backed Securities Market

5.1. Introduction

The financial crisis of 2007-2009 induced global stock markets to plummet, caused financial institutions to suffer massive losses and led economies worldwide into recession. In its aftermath it became clear that it had originated in the relatively new and small subprime mortgage-backed securities market (Gorton, 2009). Triggered by a declining real estate market and the threat of vast defaults by borrowers, particularly in the subprime sector, the crisis soon evolved from a real estate problem to a much broader global credit crisis (Brunnermeier, 2008). By September 2008 liquidity had all but come to a halt in already unstable financial markets and events such as the fall of Wall Street giant Lehman Brothers and the nationalization of insurance powerhouse AIG added to institutions' growing reluctance to lend to one another (Bordo, 2008). The U.S. government was forced to intervene in an effort to stem the spread of the crisis even further, implementing strategies such as the Emergency Economic Stabilization Act of 2008, which authorized the Treasury to spend up to $700 billion purchasing troubled assets and supplying banks with capital, causing the Act to be dubbed the "$700 billion bailout plan" by the media (Nothwehr, 2008). Despite such measures market conditions continued to deteriorate, investor confidence remained low and the crisis extended across markets and countries.

Contagion during such a catastrophic crisis is clearly of importance to investors and financial institutions and so this chapter tests for its presence from the U.S. subprime mortgage-backed securities market, represented by the ABX.HE indexes, to several fixed income, equity and volatility markets following the vector autoregressive (VAR) framework outlined by Longstaff (2010).[1] This chapter builds on Chapter 4 as it extends the test for contagion from within the U.S. subprime mortgage-backed securities market to other markets which also became distressed during the financial turmoil. As in Chapter 4 we adopt the definition of contagion presented by Forbes & Rigobon (2002) as "an episode in which there is a significant increase in cross-market linkages after a shock occurs in one market". The spliced ABX index employed by Longstaff (2010) is analysed, along with two traded ABX vintages in order to ascertain if there are notable differences across the various ABX data sets.

The analysis in Longstaff (2010) is extended to include a "post-crisis" period of 2009 and is applied to two traded ABX vintages. Principal component analysis (PCA) is then performed on the three ABX series and the main principal component is employed in a further VAR analysis.

The VAR results provide little evidence of contagion from the spliced ABX index to the financial market variables during the "post-crisis" period of 2009. Otherwise results for this index are consistent with Longstaff (2010). The VAR analysis performed on two traded ABX vintages suggests that there exist differences across vintages, as well as across the traded and spliced indexes. During 2006 the ABX 06-1 vintage and financial market variables are not subject to high levels of comovement and so behave mostly independently of the each other. There is then evidence of contagion from this index to the financial markets during the volatile 2007 "subprime-crisis" period, which dissipates during the "global-crisis" period as liquidity dried up, before increasing slightly in the 2009 "post-crisis" year, as markets rebounded.

[1] For a description of the ABX.HE indexes see Chapter 2, section 2.3.1.

Analysis of the ABX 06-2 vintage suggests that significant relationships existed between the assets during the "pre-crisis" period of 2006, indicating interdependencies among the assets, which is in striking contrast to the spliced and ABX 06-1 index. There is evidence of contagion from the ABX 06-2 vintage in 2007, however it does not affect the stock markets or general market volatility proxies in the same way as the spliced and ABX 06-1 indexes. Evidence of contagion remains strong during 2008 and 2009, again in contrast to the other indexes.

Principal component analysis (PCA) indicates that all three ABX series examined experience a fall in commonality between 2006-2009, suggesting that the importance of risk factors underlying the ABX changed as the crisis evolved. Therefore, in an effort to parsimoniously capture the effect of ABX returns we include the main principal component obtained as an explanatory variable in further VAR analysis, the results of which reinforce the original VAR analysis. Overall the results highlight the differences among the three ABX data sets analysed and suggest that splicing the ABX may impact results. It also provides evidence that the traded ABX vintages are heterogeneous assets that were subject to different risk profiles during the crisis.

The remainder of the chapter is organised as follows. Section 5.2 briefly outlines some related literature while section 5.3 describes the data employed. Section 5.4 presents preliminary analysis results and section 5.5 extends the analysis presented in Longstaff (2010) to include a "post-crisis" period of 2009. Section 5.6 discusses the VAR analysis performed on two traded ABX vintages. Section 5.7 presents the results of principal component analysis and section 5.8 includes the main principal component obtained in a further VAR analysis. A final section then concludes.

5.2. Related Literature

The subject of contagion in financial markets has been investigated extensively in recent years, providing a great deal of literature examining the subject.[2] However, there does not yet exist a general professional consensus concerning what constitutes contagion, leading to various definitions and various methods of testing for its presence. Pericoli & Sbracia (2003) present and discuss five frequently applied definitions of contagion while Dungey et al. (2005) analyse methodologies used to test for contagion and develop an encompassing factor-based model.[3]

There is a growing body of work analysing contagion during the subprime crisis, for example Kim et al. (2010) investigate CDS spread fluctuations and expected default frequencies for Asian borrowers, finding that losses are due to both global and region-specific factors, while Cheung et al. (2010) examine relationships between global equity markets and the TED spread, finding that linkages among global stock markets increase during the crisis and the TED spread acts as a "fear" indicator.[4] Abbassi & Schnabel (2009) employ a VAR framework on U.S., U.K. and Euro area data in order to analyse whether contagion may explain increasing repurchase agreement spreads. Evidence of contagion in interbank money markets during 2007 is found and it is suggested that liquidity problems are the main cause of this.

Liquidity and contagion during the subprime crisis are discussed by Adrian & Shin (2008). Analysing the effect of asset price changes on a hypothetical balance sheet, they highlight the "puzzle" of such a relatively small market causing widespread chaos and suggest that asset prices alone may be sufficient to generate contagion.

[2] See Chapter 4, section 4.2 for a brief overview of contagion literature.

[3] For a comprehensive overview of various definitions of contagion, along with various methodologies utilized to test for its presence, see Forbes & Rigobon (2001B).

[4] The TED spread is the difference between the interest rates on interbank loans and on short-term U.S. government debt.

Hwang et al. (2010) examine contagion effects from the U.S. subprime mortgage crisis to international stock markets using a dynamic conditional correlation generalized autoregressive conditional heteroskedastic (DCC-GARCH) model. During the subprime crisis evidence of contagion in both emerging and developed countries is found, along with evidence of a spillover effect of news concerning sovereign credit ratings.

Lee (2012) utilizes heteroskedasticity bias based on correlation coefficients on twenty international stock markets, finding evidence of contagion in Hong Kong, Australia, Taiwan and New Zealand.

Horta et al. (2008) employ a copula model in order to investigate whether the U.S. subprime crisis affected the capital markets of several developed countries, finding evidence of contagion with varying intensity across countries.

Despite the increasing body of literature examining contagion during the subprime crisis, literature utilizing the ABX indexes to test for its presence during 2007-2009 is not as extensive. Longstaff (2010) utilizes the ABX indexes to represent the U.S. subprime mortgage-backed securities market and tests for contagion from this proxy to several fixed income, equity and volatility markets using a VAR framework.[5]

5.3. Data

This chapter treats Longstaff (2010) as the benchmark for testing for contagion from the ABX indexes and so employs the spliced ABX index and financial market variables utilized by that work. Data from two traded ABX indexes, the ABX 06-1 vintage and the ABX 06-2 vintage, are also analysed in order to ascertain if splicing the data could

[5] For more on this see Chapter 4 section 4.2.

influence the results.[6] ABX data have been obtained from the Markit Group and weekly (Wednesday to Wednesday) percentage returns are used in the analysis for the period spanning 2006-2009. Following Longstaff (2010), the sample is divided into one-year samples, with the labels "'pre-crisis", "subprime-crisis", "global-crisis" and "post-crisis" applied to calendar years 2006, 2007, 2008 and 2009, respectively.

5.3.1. Financial Market Variables

Longstaff (2010) employs weekly returns of the five assets comprising the spliced ABX index to proxy for returns in the troubled subprime mortgage-backed CDO market. A VAR framework is employed to test for contagion from this market to several equity, volatility and fixed-income markets. Weekly changes in the constant maturity one- and 10-year Treasury yields are included to capture changes in the Treasury bond market while changes in corporate bond spreads are measured as the difference between the 10-year Treasury yield and Moody's Aaa and Baa corporate yield indexes. Treasury yield and corporate yield data have been obtained from the Federal Reserve Board. Weekly returns for the S&P 500 index and the S&P 500 subindex of financial firms capture changes in the U.S. stock market while changes in the VIX volatility index provide a measure of market volatility. Data for these three VAR variables have been obtained from the Bloomberg system.

[**Insert Figure 5.1 about here**]

Figure 5.1 plots the time series of these VAR variables over the entire sample period. While the corporate spreads and VIX index are quite volatile throughout, the S&P 500

[6] The spliced ABX index is described in Chapter 4 section 4.3.1.

index and S&P 500 subindex of financial firms become most volatile around mid-2008, which coincides with the onset of the global credit crunch and increased volatility in stock markets. Changes in the two Treasury yields become increasingly volatile from 2007 onwards, with the shorter maturity one-year bill experiencing most volatility in 2008. In fact, during that year the one-year constant maturity Treasury rate fell from 2.71% in January to 0.49% in December (Federal Reserve Board). The 10-year bond continues to be quite volatile during the "post-crisis" period of 2009. This longer maturity bonds' rate ranges from a high of 5.25% to 2.20% over the sample period, with the lowest values experienced from the end of 2008 through early 2009. These movements are illustrated in Figure 5.2, which plots the two Treasury Bill rates over the sample period.

[**Insert Figure 5.2 about here**]

As Mc Andrews et al. (2008) state, these Treasury securities contain liquidity premia, with the 10-year bond usually containing larger liquidity than other Treasury bonds. It is possible then that weekly changes in this longer maturity bond experience a greater degree of volatility relative to the one-year Treasury Bill during the 2008-2009 period because of the effects of the liquidity freeze in mid- to late-2008.

Table 5.1 provides summary statistics for weekly changes in each of the financial market variables over the entire sample period.

[**Insert Table 5.1 about here**]

Not surprisingly, we observe negative means for the stock market and Treasury bond market measures and positive means for weekly changes in the VIX index and the two corporate spreads. Volatility is high for each financial market variable, but is highest for changes in the two Treasury Bills. As stated above, these Treasury notes are known to contain liquidity premia (Mc Andrews et al. 2008) and high levels of volatility during the subprime and liquidity crisis periods. It is clear that normality is rejected in all cases, with the S&P 500 index experiencing the highest level of excess kurtosis, which is unsurprising for stock returns (Campbell & Hentschel, 1992).

5.4. Preliminary Analysis

Table 5.2 reports summary statistics for weekly percentage returns of the three ABX series under analysis over the sample period.

[**Insert Table 5.2 about here**]

Mean returns are negative in all asset tranches, and are monotonically related to credit rating in the three indexes suggesting that these lower-rated securities were hit hardest over the sample period. Standard deviations are high in all cases, indicating the high volatility of returns. They do not appear to be inversely related to credit rating as, based on these, the AA-rated asset is most volatile in the spliced ABX index, while the BBB-rated asset is most volatile in the ABX 06-1 vintage and the A-rated asset the most volatile in the ABX 06-2 vintage. This highlights differences between the three indexes, suggesting that they are distinct assets in which ratings tranches behave differently. Unsurprisingly almost all returns are negatively skewed and it is clear that normality is rejected in all cases. As a preliminary examination of the relationships between the assets Table 5.3 reports raw correlation coefficients between the five ABX tranches in each index and the financial market variables over the entire sample period.

[**Insert Table 5.3 about here**]

The ABX assets are positively correlated with the stock market and Treasury market measures, suggesting that a decline in ABX returns corresponds to a decline in these variables, and vice versa. Unsurprisingly the VIX index and corporate spread measures are negatively correlated with ABX returns, indicating that a decrease in ABX returns corresponds to an increase in market volatility and a widening of credit spreads. Although these correlations imply that ABX returns are positively related to changes in the stock market and Treasury market and negatively related to volatility and corporate spreads this relationship may exist in "normal" market times and so it is necessary to test for co-movement in excess of what is expected in tranquil conditions.

5.5. Extending Longstaff

We first replicate the results of Longstaff (2010), utilizing the VAR system employed by that work:

$$Y_t = \alpha + \sum_{k=1}^{4} (\beta_k Y_{t-k} + \gamma_k ABX_{t-k}) + \epsilon_t, \tag{5.1}$$

in which Y_t denotes the financial market measure included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. ABX_{t-k} denotes the ABX asset included as an exogenous variable. As there are five ratings classes there are five ABX assets in each ABX series and so the VAR system is estimated for each of these. Also, as mentioned earlier the data are broken into distinct one-year periods. Four lags are suggested by the Akaike Information Criterion (AIC). Despite some limitations to this methodology, which will be addressed in the subsequent chapter, its greatest advantage lies in its ability to incorporate many financial variables simultaneously. Tables 5.4 - 5.7 report results from the VAR performed on the spliced ABX index for 2006, 2007, 2008, and 2009, respectively. As the residuals are likely to have a non-constant variance, we follow Longstaff (2010) by computing Newey-West adjusted standard errors. We therefore report the Newey–West t-statistics for the γ_k coefficients in equation (5.1) along with the R^2s from the VARs and the p-values for the F-test that the γ_k coefficients are jointly zero.[7]

[**Insert Tables 5.4 - 5.7 about here**]

There is little evidence of Granger-causality from the ABX returns to the financial market variables during 2006. This is in striking contrast to the results presented for 2007, in which almost all assets are significantly affected by the spliced ABX returns. It is this difference that constitutes contagion as it provides evidence of a significant increase in cross-market linkages following a shock to the subprime mortgage-backed securities market. Evidence of contagion then dissipates during 2008, with the onset of the liquidity crisis. There is little evidence of contagion in 2009. The two stock market measures are significantly affected by only the AA-rated ABX asset, while there is almost no evidence of contagion from the ABX to the one-year Treasury Bill yield. The two credit spreads are most significantly affected by ABX returns relative to the other financial market variables, which could be due to credit markets rebounding

[7]Note that the results for the β coefficients are not reported in order to conserve space and also as they do not provide any information regarding contagion from the ABX to the financial market variables. Full results are available on request.

following the liquidity crunch. These results support those presented in Longstaff (2010) that contagion occurred from the spliced ABX returns to the financial market variables in 2007 before dissipating in subsequent years.

5.6. Traded ABX Vintages VAR Analysis

The VAR framework presented in equation (5.1) is applied to two traded ABX vintages, the ABX 06-1 vintage and the ABX 06-2 vintage. In Longstaff (2010) the analysis is characterized by a tranquil period in which the ABX assets are independent of the financial market variables, so enabling to test whether there exist significant increases in the linkages between the assets following the onset of the crisis. We must therefore establish that interdependencies between the traded indexes and the assets do not exist during 2006 in order to appropriately apply the framework. Table 5.8 reports the VAR estimation results for the tranquil "pre-crisis" period of 2006 for the ABX 06-1 vintage.

[**Insert Table 5.8 about here**]

There is little evidence of Granger-causality from ABX returns to the financial market variables analysed as well as little evidence of price discovery during this tranquil period, as few of the individual t-statistics are significant. This would suggest that during 2006 these markets behave mostly independently of each other and are not subject to high levels of interdependencies. This allows us to therefore test for co-movement over and above what is expected in "normal" market conditions. Tables 5.9, 5.10 and 5.11 report VAR estimation results for 2007, 2008 and 2009, respectively, for the ABX 06-1 vintage VAR estimation.

[**Insert Tables 5.9 - 5.11 about here**]

In 2007 almost every asset in the ABX 06-1 vintage Granger-causes subsequent changes or returns in the financial market variables and the R^2s are all quite high, particularly relative to those reported for 2006. As this represents a significant change in the relationship between these assets these results provide evidence of contagion from the ABX 06-1 vintage to the financial market variables during the “subprime-crisis” period of 2007.

Turning first to the two Treasury Bill yields, we see that all F-statistics are significant, compared to very little significance in 2006, and there is significant predictive ability of at least three weeks ahead in all cases. All significant t-statistics are positive in sign, suggesting that a decrease in ABX returns corresponds to a decrease in Treasury yields, thus indicating an increase in the value of Treasury bonds. This would suggest that investors were turning to these “risk-free” securities during this turbulent crisis period, thus indicating a flight-to-quality to “safe-haven” assets.

Turning to the two credit spreads, all F-statistics are significant, which is in striking contrast to the results presented for 2006. In all cases ABX returns Granger-cause subsequent changes in both the Moody’s Aaa and Baa corporate spreads by up to four weeks ahead, and all significant t-statistics are negative in sign. This suggests that a decline in ABX returns corresponds to a widening of these corporate spreads during the 2007 crisis period.

Almost all ABX asset returns have significant predictive power for subsequent returns in both the S&P 500 index and the S&P 500 subindex of financial firms during the subprime crisis. Almost all ratings tranches of the ABX have significant forecast ability of up to four weeks ahead during 2007, and all significant coefficients are positive in sign, indicating that a negative shock to ABX returns translates to negative returns in these stock indexes.

The results for the VIX index suggest that almost all ABX assets Granger-cause subsequent changes in this index of the markets perception of volatility. The individual t-statistics indicate significant price discovery of up to three weeks ahead during the subprime crisis, and all significant coefficients are negative in sign, suggesting that a shock to ABX returns translates to an increase in the VIX index. However, there is slightly less evidence of contagion from the ABX 06-1 vintage to the VIX in 2007 than from the spliced ABX index, indicating a stronger relationship between the riskier index to the measure of market volatility.

Table 5.10 indicates that evidence of contagion decreases in 2008 relative to the "subprime-crisis" period of 2007. During the "global-crisis" period the only ABX asset that consistently Granger-causes each financial variable analysed is the AAA-rated tranche, while the two lower-rated assets show no significant forecast power at all. One possible reason for this could be that during this period liquidity in financial markets had come to almost a complete halt, as had trades in the now perceived to be "toxic" ABX. Also, most of the lower tranches would have been wiped out by defaults so it is likely then that the only ABX asset with any liquidity during this time would be the highest-rated tranche, causing most contagion effects to emanate from this asset.

There is more evidence of contagion during the "post-crisis" period than during the "global-crisis" period, which could be due to financial markets starting to bounce back as investors began to re-enter following the crisis years. The two corporate spreads are most vulnerable to contagion from the subprime mortgage-backed securities, which could be due to remaining instability in credit markets following the crisis. There is little evidence of contagion to the two Treasury Bill yields, consistent with investors no longer requiring a "safe haven" in this post-crisis era. There is slightly more evidence of contagion from this index during 2008 and 2009 than from the spliced ABX index, indicating that more linkages remained between the ABX 06-1 vintage and financial markets in these years than between them and the spliced ABX index.

Turning to the ABX 06-2 vintage, issued on July 19, 2006. The results from the VAR model presented in equation (5.1) provide evidence of interdependencies during the "pre-crisis" of 2006. This implies that the above VAR framework cannot be employed to test for linkages in excess of those experienced in "normal" market times. We therefore follow the methodology outlined in Chapter 4 and incorporate dummy variables to account for crisis periods. We define three dummy variables. To account for the "subprime-crisis" period of 2007 a dummy variable, $D1$, is included, taking a value of one during 2007 and zero otherwise. To account for the "global-crisis" period of 2008 a dummy variable, $D2$, is included, taking a value of one during 2008 and zero otherwise. To account for the "post-crisis" period of 2009 a dummy variable, $D3$, is included, taking a value of one during 2009 and zero otherwise. The dummy variables are thus defined as:

$$D1 = \begin{cases} 0 \text{ if } 2006 \\ 1 \text{ if } 2007 \\ 0 \text{ if } 2008 \\ 0 \text{ if } 2009 \end{cases}, \quad D2 = \begin{cases} 0 \text{ if } 2006 \\ 0 \text{ if } 2007 \\ 1 \text{ if } 2008 \\ 0 \text{ if } 2009 \end{cases}, \quad D3 = \begin{cases} 0 \text{ if } 2006 \\ 0 \text{ if } 2007 \\ 0 \text{ if } 2008 \\ 1 \text{ if } 2009 \end{cases}.$$

These dummy variables are then included in the following model:

$$
\begin{aligned}
Y_t = \alpha_0 + \sum_{k=1}^{2} \beta_k Y_{t-k} + \sum_{k=1}^{2} \gamma_k ABX_{t-k}, \\
+\delta_0 D1 + \sum_{k=1}^{2} D1(\beta_k - \lambda_k) Y_{t-k} + \sum_{k=1}^{2} D1(\gamma_k - \upsilon_k) ABX_{t-k}, \\
+\theta_0 D2 + \sum_{k=1}^{2} D2(\beta_k - \delta_k) Y_{t-k} + \sum_{k=1}^{2} D2(\gamma_k - \eta_k) ABX_{t-k}, \\
+\phi_0 D3 + \sum_{k=1}^{2} D3(\beta_k - \psi_k) Y_{t-k} + \sum_{k=1}^{2} D3(\gamma_k - \tau_k) ABX_{t-k}, \\
+\epsilon_t,
\end{aligned} \tag{5.2}
$$

in which α_0 denotes the 2006 constant term, $\delta_0 D1$ denotes the 2007 constant term, $\theta_0 D2$ denotes the 2008 constant term, $\phi_0 D3$ denotes the 2009 constant term, Y_t denotes the financial market variable included as a dependent variable, ABX_{t-k} denotes the ABX asset weekly percentage returns included as an independent variable. Two lags are determined by the Akaike Information Criterion. This analysis allows us to test the stability of the regression coefficients and if the coefficients on the dummy variables are significant we conclude that contagion occurred. Table 5.12 reports VAR estimation results for 2006, 2007, 2008 and 2009, respectively. Reported are the p-values of the F-test that the indicated variables are jointly zero.

[**Insert Table 5.12 about here**]

There is clearly evidence of interdependencies among the assets during the "pre-crisis" period as changes or returns in almost all financial market variables are Granger-caused by ABX returns. This is in striking contrast to the results presented for both the spliced and the ABX 06-1 vintage, as during the tranquil period assets in these two indexes behave mostly independently of the financial market variables. Turning to the 2007 "subprime-crisis" period there is evidence of contagion from the ABX 06-2 vintage to Treasury markets, corporate bond markets and the S&P 500 subindex of financial firms. However, there is no evidence of contagion whatsoever from this index to the S&P 500 index, suggesting that the ABX 06-2 vintage has no significant effect upon S&P 500 index returns during 2007. It appears that its influence on stock prices is limited to financial stocks. This is also in contrast to the results presented for both the spliced ABX index and the ABX 06-1 vintage. Also, the VIX index is significantly affected by only the two lower-rated assets during the subprime crisis, suggesting that any risk transmitted to this measure of market volatility came from the riskier ABX assets. In 2008 evidence of contagion actually increases, as now the S&P 500 index is significantly affected by ABX returns. The only variable to which evidence of contagion dissipates is the VIX index, which contrasts again to the results presented for the spliced and 06-1 indexes. During the "post crisis" period of 2009 evidence of contagion to the stock market proxy completely dissipates, indicating that there is no change in the relationship between these markets in this year relative to 2006. Overall, these results suggest that there was a significant change in the relationship between the assets comprising all three ABX indexes and the financial variables analysed, indicating contagion under our definition and framework. Significant price discovery indicates that this contagion was not transmitted through the "correlated information" channel of contagion, as in this channel price changes should be instantaneous, and supports the "risk-premium" channel of contagion, in which the distressed security holds predictive power for subsequent returns of other assets.[8] Evidence of contagion dissipates during the 2008 "global-crisis" period as liquidity came to a halt, then increases somewhat

[8]For a detailed description of these channels for contagion see Chapter 4, section 4.2.

during the 2009 "post-crisis" period, most likely because of markets rebounding following the crisis.

The results highlight some striking differences between the indexes analysed as there is strong evidence of interdependencies among the assets in the ABX 06-2 vintage and the financial market variables in 2006, while no such relationship exists between the ABX 06-1 vintage and the financial variables. As Dungey et al. (2013) state these assets are *"distinct in vintage of issuance"* and our results also suggest that the two traded vintages behave differently, reinforcing the heterogeneous nature of these assets. There are also differences between the traded vintages and the spliced ABX index, for example there is more evidence of contagion during the "global-" and "post-crisis" periods from the traded vintages. This suggests that analysis of the spliced ABX index alone may not provide a full and accurate picture of what was happening in this market over the sample period. The sensitivity of these results is tested by including ABX returns as an eighth endogenous variable in the VAR system, the results of which correspond to the original results.[9]

5.7. Principal Component Analysis

In order to reduce the dimensionality of the noisy ABX returns principal component analysis (PCA) is performed on the five assets comprising each ABX series under analysis separately for each of the four years, 2006, 2007, 2008, and 2009.[10] With noisy data such as the ABX we utilize these principal components in further analyses in place of ABX returns in an effort to achieve clearer results. Figures 5.3, 5.4 and 5.5

[9] Full results are available on request.

[10] See Chapter 3, section 3.6, for a detailed explanation of PCA.

present the relative importance of the principal components obtained in each of the four years under consideration for each ABX series analysed.

[**Insert Figures 5.3 - 5.5 about here**]

Figure 5.3 illustrates that, on average, the main principal component underlying the spliced ABX index falls by almost 40% between 2006 and 2009. This indicates that the importance of the factors driving the variation in the spliced ABX index returns changed over the sample period and commonality fell with each subsequent year. Turning to Figure 5.4, the relative importance of the main principal component underlying the ABX 06-1 vintage remains almost constant between 2006 and 2007 before declining by almost 20% by the end of the sample. This would suggest that the "global-crisis" period of 2008 and subsequent "post-crisis" period of 2009 had a greater effect on the common factors driving variation in the ABX 06-1 vintage than the "subprime-crisis" period of 2007.

Figure 5.5, illustrating the relative importance of the principal components underlying the ABX 06-2 vintage, indicates that again the relative importance of the main principal component is quite high in 2006, suggesting a high degree of commonality in the ABX 06-2 vintage during this "pre-crisis" year. This commonality then decreases once the "subprime-crisis" period hits, and continues to fall until the end of the sample. Overall, these results indicate that the three ABX series were all subject to a high degree of commonality during the tranquil 2006 period. For the ABX 06-1 vintage this commonality remains throughout the subprime crisis, but both the spliced index and the 06-2 vintage experience falls of almost 10% between the two years. Once the "global-crisis" period of 2008 occurs, the main principal component in all three indexes falls by almost 10%, and continues to fall through the "post-crisis" period. The spliced

ABX index experiences the greatest loss of commonality, which is unsurprising due to its construction.

5.8. VAR Analysis using Principal Components

The VAR analysis presented in equation (5.1) is performed using the main principal component obtained as an exogenous variable, instead of ABX returns, thus testing if the main principal component Granger-causes subsequent changes or returns in the seven financial market variables. The VAR specification therefore becomes:

$$Y_t = \alpha + \sum_{k=1}^{4} (\beta_k Y_{t-k} + \gamma_k PC_{1,t-k}) + \epsilon_t, \tag{5.3}$$

in which Y_t denotes the financial market measure, as described in section 5.3, included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. PC_1 denotes that principal component 1 is the exogenous variable. Four lags are suggested by the Akaike Information Criterion (AIC). Tables 5.13, 5.14 and 5.15 report VAR estimation results using returns from each of the three ABX data sets under consideration.

[**Insert Tables 5.13 - 5.15 about here**]

Overall these results provide evidence of contagion from the ABX 06-1 vintage main principal component to the financial market variables, along with significant price discovery. There is evidence of interdependencies between the ABX 06-2 vintage main principal component and the financial market variables in 2006, again indicating that any evidence of linkages observed in subsequent crisis periods does not constitute contagion, which corresponds to earlier results. Evidence of contagion from the spliced ABX index main principal component is not as strong as there also exist interdependencies during 2006.

5.9. Conclusions

This chapter analyses contagion from the U.S. subprime mortgage-backed securities market, using the ABX.HE indexes to represent this market, via the VAR framework presented in Longstaff (2010). The analysis in Longstaff (2010) is extended to include a "post-crisis" period of 2009 and is applied to two traded ABX vintages. Principal component analysis (PCA) is performed on the three indexes under consideration and the main principal component is included in further a VAR analysis to investigate if eliminating noise from the returns process provides clearer results.

The results provide little evidence of contagion from the spliced ABX index to the financial market variables during the "post-crisis" period of 2009, as markets bounced back following the crisis. Analyses of the traded ABX indexes provide evidence of contagion during the crisis periods, however there are several key differences between the results for the two vintages. Firstly, there is evidence of interdependencies among the assets in the ABX 06-2 vintage and the financial markets analysed in the "pre-crisis" period of 2006, a relationship not observed between the ABX 06-1 vintage assets and the other financial markets. Secondly, there is no evidence of contagion from the ABX 06-2 vintage to the S&P 500 index, while our results show strong evidence of contagion from the ABX 06-1 vintage to equity markets. Finally, there is considerably more evidence of contagion from the ABX 06-2 vintage to the other financial markets in the subsequent “global-crisis” and “post-crisis” period than from the earlier issued vintage. These results highlight the heterogeneous nature of the ABX vintages, a finding consistent with Dungey et al. (2013). Our results also highlight differences between the traded ABX indexes and the spliced ABX index employed by Longstaff (2010). For example, we find more evidence of contagion from the ABX 06-1 vintage to corporate bond and equity markets in the “post-crisis” period of 2009, indicating continuing significant linkages between these markets following the crisis. This indicates that analysis of the spliced ABX index may not provide and accurate depiction of what was happening in these markets over the sample period.

Figure 5.1: Financial Market Variables.
This figure illustrates weekly changes of the indicated financial market variables.

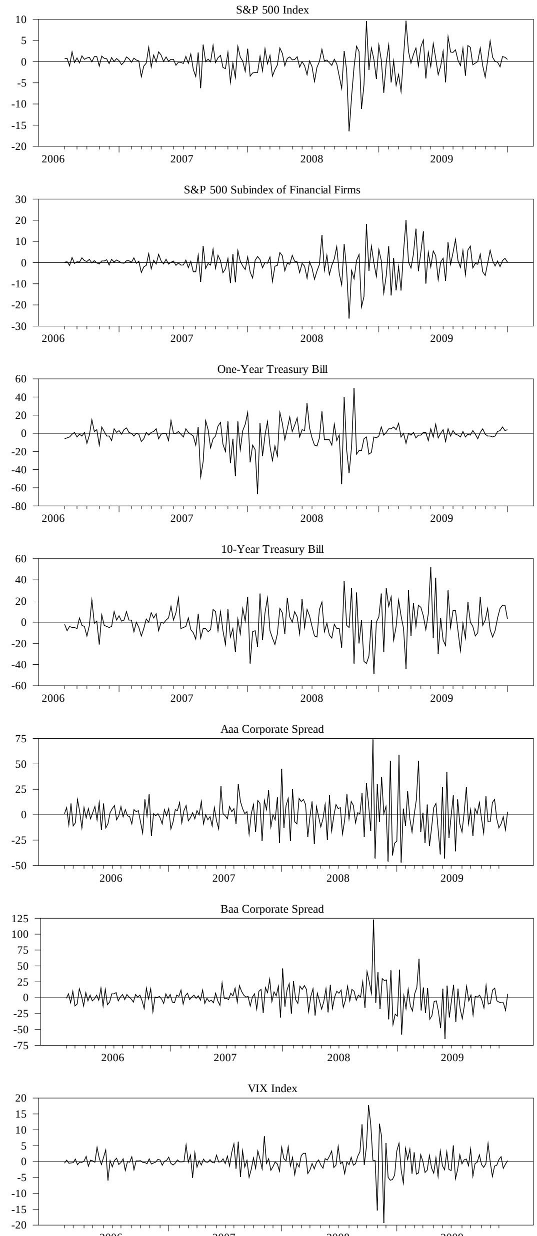


Figure 5.2: Treasury Bill Rates.

Figure 5.3: Relative Importance of Spliced ABX Index Principal Components. This Figure illustrates the relative importance of principal components underlying the spliced ABX index for the indicated year.

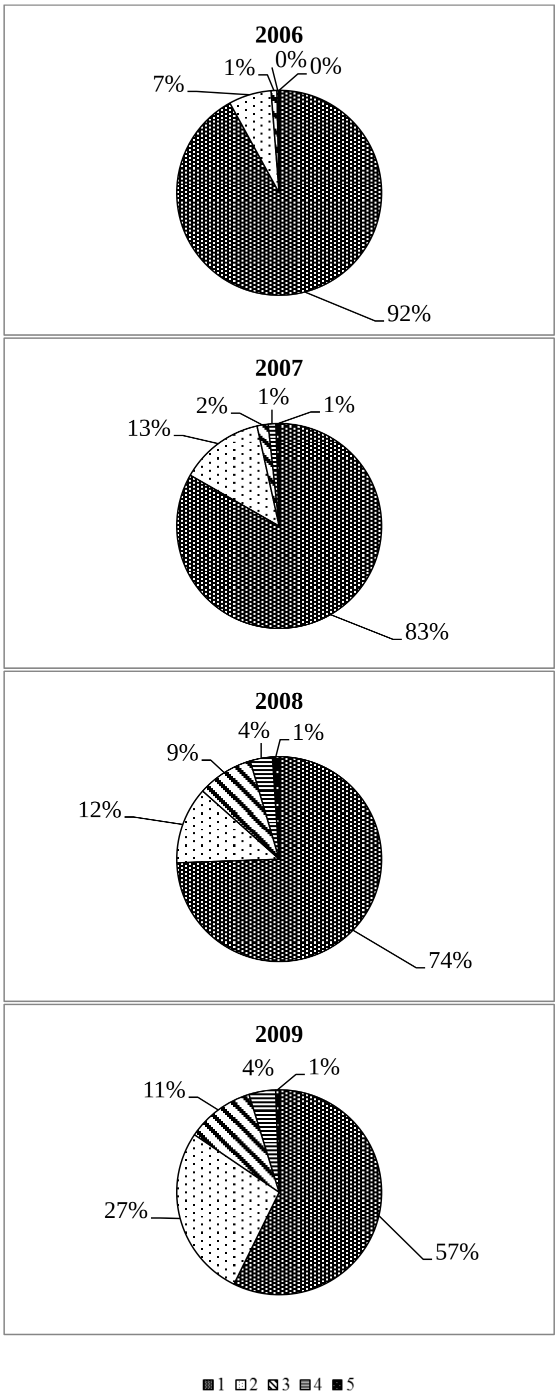


Figure 5.4: Relative Importance of ABX 06-1 Vintage Principal Components. This Figure illustrates the relative importance of principal components underlying the ABX 06-1 vintage for the indicated year.

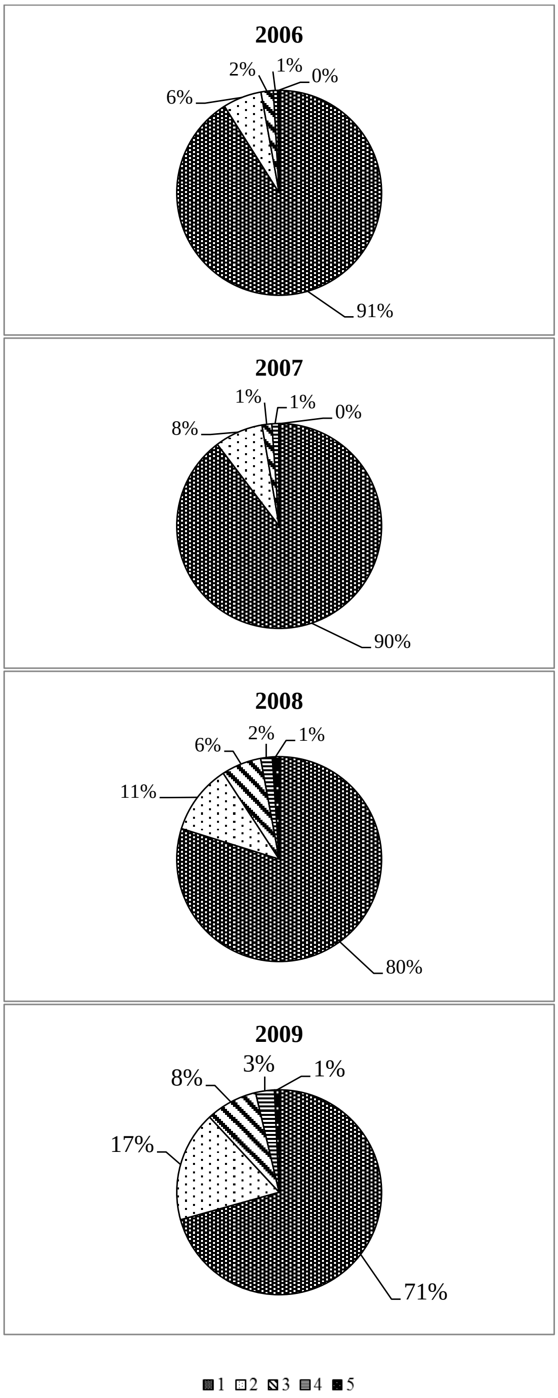


Figure 5.5: Relative Importance of ABX 06-2 Vintage Principal Components.This Figure illustrates the relative importance of principal components underlying the ABX 06-2 vintage for the indicated year.

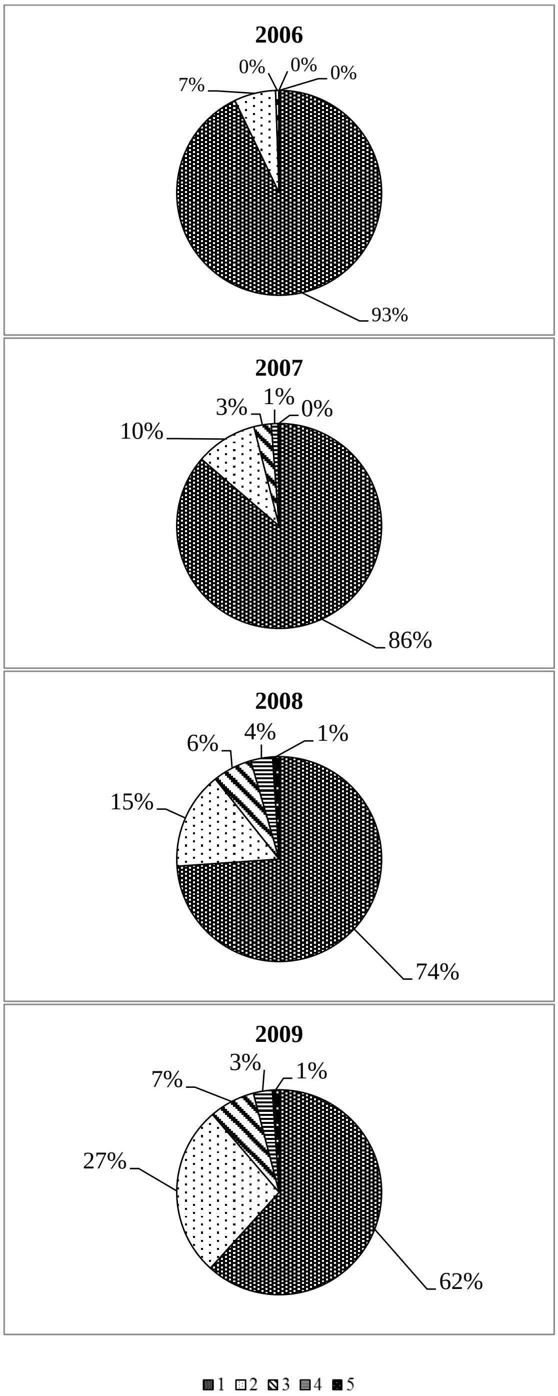


Table 5.1: Financial Market Variables Summary Statistics

Notes: This table reports summary statistics for weekly changes ib the indicated financial market variable for the entire sample period. Std. Dev. denotes standard deviation; Min. denotes minimum; Max. denotes maximum.The sample ranges from January 19, 2006, to December 31, 2009.

Variable	Mean	Std.dev.	Skewness	Kurtosis	Min.	Max
S&P 500 Index	-0.015	2.847	-0.855	5.374	-15.169	10.118
S&P 500 Subindex	-0.153	5.504	0.039	4.234	-23.208	22.192
One-Year T-bill	-1.980	13.412	-1.058	5.869	-67.000	50.000
10-Year T-bill	-0.377	15.307	-0.023	1.214	-49.000	52.000
VIX Index	0.935	12.447	1.104	2.783	-29.415	51.176
Aaa Corporate Spread	1.016	11.929	0.905	2.637	-22.951	59.574
Baa Corporate Spread	0.378	5.864	0.673	2.491	-14.541	26.216

Table 5.2: Summary Statistics For ABX Weekly Percentage Returns

Notes: This table reports summary statistics for weekly percentage returns of the indicated ABX asset for the entire sample period. Std. Dev. denotes standard deviation; Min. denotes minimum; Max. denotes maximum.The sample ranges from January 19, 2006, to December 31, 2009.

Data set	Rating	Mean	Std.dev.	Skewness	Kurtosis	Min.	Max
Spliced ABX Index	AAA	-0.432	4.749	-0.072	2.709	-16.573	14.839
	AA	-1.338	5.852	-1.453	7.266	-29.754	21.416
	A	-1.410	5.799	-1.420	5.811	-28.786	18.773
	BBB	-1.604	4.764	-1.116	3.825	-21.429	13.595
	BBB-	-1.572	4.950	-1.107	4.468	-26.617	12.941
ABX 06-1 Vintage	AAA	-0.068	2.599	-0.555	9.487	-14.933	12.209
	AA	-0.386	5.571	0.720	11.475	-26.347	35.223
	A	-0.889	6.058	0.027	3.920	-19.908	24.216
	BBB	-1.323	5.762	-1.535	8.032	-32.947	21.367
	BBB-	-1.349	5.143	-1.978	7.814	-27.130	16.264
ABX 06-2 Vintage	AAA	-0.316	4.908	-0.495	3.794	-21.611	15.598
	AA	-1.209	6.255	-0.043	3.183	-22.713	22.821
	A	-1.447	6.400	-1.219	4.415	-30.747	14.484
	BBB	-1.442	6.398	-0.079	3.318	-23.259	25.172
	BBB-	-1.475	5.922	0.174	3.1364	-19.075	23.809

Table 5.3: Raw Correlation Coefficients

Notes: This table reports raw correlation coefficients between the indicated variables (in weekly percentage changes) for the entire sample period. The sample ranges from January 19, 2006, to December 31, 2009.

Spliced ABX					
	AAA	AA	A	BBB	BBB-
S&P 500 Index	-0.04	0.01	0.02	0.11	0.06
S&P 500 Subindex	-0.07	-0.01	-0.03	0.05	0.03
One-Year T-bill	0.15	0.26	0.24	0.15	0.10
10-Year T-bill	0.31	0.32	0.30	0.19	0.18
VIX Index	0.05	-0.05	-0.07	-0.17	-0.13
Aaa Corporate Spread	-0.23	-0.16	-0.16	-0.08	-0.05
Baa Corporate Spread	-0.30	-0.22	-0.21	-0.12	-0.08
ABX 06-1 Vintage					
	AAA	AA	A	BBB	BBB-
S&P 500 Index	0.36	0.37	0.25	0.24	0.25
S&P 500 Subindex	0.38	0.42	0.27	0.26	0.27
One-Year T-bill	0.12	0.18	0.19	0.25	0.27
10-Year T-bill	0.25	0.19	0.20	0.18	0.20
VIX Index	-0.22	-0.25	-0.22	-0.20	-0.21
Aaa Corporate Spread	-0.18	0.13	-0.12	-0.20	-0.21
Baa Corporate Spread	-0.17	-0.15	-0.12	-0.18	-0.20
ABX 06-2 Vintage					
	AAA	AA	A	BBB	BBB-
S&P 500 Index	0.42	0.24	0.21	0.16	0.17
S&P 500 Subindex	0.44	0.27	0.21	0.16	0.17
One-Year T-bill	0.13	0.13	0.14	0.16	0.18
10-Year T-bill	0.21	0.17	0.17	0.14	0.14
VIX Index	-0.27	-0.19	-0.15	-0.15	-0.17
Aaa Corporate Spread	-0.18	-0.10	-0.15	-0.15	-0.14
Baa Corporate Spread	-0.17	-0.11	-0.14	-0.16	-0.16

Table 5.4: Spliced ABX Index 2006 VAR Estimation Results

Notes: This table reports results from the following VAR estimation:

$$y_t = \alpha + \sum_{k=1}^{4} \beta_k Y_{t-k} + \gamma_k ABX_{t-k} + \epsilon_t,$$

in which y_t denotes the financial market measure included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. ABX_{t-k} denotes the ABX asset included as an exogenous variable. As there are five ratings classes there are five ABX assets in each ABX series and so the VAR system is estimated for each of these. Four lags are suggested by the Akaike Information Criterion (AIC). Reported are Newey-West adjusted t-statistics, R^2s and p-values of the F-test that the γ coefficients are jointly zero. T-statistics are reported in parentheses. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Y	ABX	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	AAA	-1.04	-0.30	0.29	0.29	0.08	0.91
	AA	0.18	1.48	0.01	0.78	0.06	0.98
	A	-1.22	1.02	-1.21	-1.04	0.15	0.41
	BBB	-1.47	0.21	0.33	-0.55	0.08	0.91
	BBB-	-0.74	0.85	-0.56	-0.31	0.07	0.93
10-Year T-bill	AAA	0.31	-0.25	1.33	0.65	0.07	0.89
	AA	2.89**	2.64**	1.24	0.52	0.17	0.27
	A	-0.45	0.52	-1.37	-0.92	0.11	0.65
	BBB	-0.74	-0.41	-0.81	0.36	0.06	0.94
	BBB-	-0.48	0.91	-1.44	0.13	0.08	0.87
Aaa Corporate Spread	AAA	1.59	0.16	0.92	-0.98	0.16	0.37
	AA	2.17**	0.44	1.58	-1.57	0.28	0.04**
	A	1.55	-1.30	1.27	-1.06	0.18	0.28
	BBB	1.51	-0.98	0.43	-0.16	0.10	0.76
	BBB-	-1.45	-1.02	1.14	-0.01	0.11	0.70
Baa Corporate Spread	AAA	0.49	-1.46	−2.09**	-0.68	0.17	0.40
	AA	-1.08	-0.39	-0.16	-1.46	0.24	0.12
	A	1.11	−2.18**	0.25	-0.57	0.20	0.24
	BBB	0.87	−1.87*	-0.02	0.13	0.13	0.68
	BBB-	0.37	−1.86*	0.06	0.01	0.13	0.63
S&P 500 Subindex	AAA	-1.36	-0.45	-0.96	0.86	0.19	0.19
	AA	−3.56**	-0.36	-0.49	0.75	0.22	0.35
	A	−2.11**	-1.31	-1.09	0.65	0.17	0.17
	BBB	-0.87	-1.25	−1.97*	0.73	0.20	0.48
	BBB-	-1.54	-1.27	-0.64	0.54	0.18	0.61
S&P 500 Index	AAA	-1.53	-0.04	-0.91	1.16	0.27	0.29
	AA	−4.11**	-0.21	-0.82	1.04	0.30	0.18
	A	-1.33	-0.93	-1.17	0.79	0.28	0.26
	BBB	-0.62	-1.14	-1.41	1.20	0.23	0.55
	BBB-	-0.98	-1.08	-0.22	0.78	0.20	0.80
VIX Index	AAA	1.14	-0.25	-0.86	-0.77	0.18	0.70
	AA	2.10**	-1.09	0.23	-0.46	0.16	0.84
	A	1.41	0.13	-0.10	0.69	0.20	0.54
	BBB	1.62	-0.35	-0.62	0.17	0.16	0.86
	BBB-	1.71*	-0.14	-1.29	1.09	0.20	0.48

Table 5.5: Spliced ABX Index 2007 VAR Estimation Results

Notes: This table reports results from the following VAR estimation:

$$y_t = \alpha + \sum_{k=1}^{4} \beta_k Y_{t-k} + \gamma_k ABX_{t-k} + \epsilon_t,$$

in which y_t denotes the financial market measure included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. ABX_{t-k} denotes the ABX asset included as an exogenous variable. As there are five ratings classes there are five ABX assets in each ABX series and so the VAR system is estimated for each of these. Four lags are suggested by the Akaike Information Criterion (AIC). Reported are Newey-West adjusted t-statistics, R^2s and p-values of the F-test that the γ coefficients are jointly zero. T-statistics are reported in parentheses. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Y	ABX	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	AAA	0.04	2.52**	1.90*	-0.28	0.40	0.00**
	AA	2.59**	1.36	3.44**	-0.61	0.48	0.00**
	A	-0.12	1.03	7.05**	2.06**	0.54	0.00**
	BBB	0.49	-0.18	3.75**	2.45**	0.43	0.00**
	BBB-	0.83	-0.11	3.56**	2.66**	0.39	0.00**
10-Year T-bill	AAA	-0.46	7.02**	2.00**	-0.22	0.33	0.01**
	AA	0.97	1.90*	1.71*	0.32	0.28	0.03**
	A	0.66	0.99	3.50**	1.97*	0.23	0.01**
	BBB	1.65	0.17	2.09**	1.92*	0.33	0.01**
	BBB-	2.68**	-0.32	2.34**	2.65**	0.39	0.00**
Aaa Corporate Spread	AAA	1.01	−3.07**	−2.62**	1.81*	0.34	0.02**
	AA	-0.54	-1.31	−7.28**	2.07**	0.41	0.00**
	A	0.46	-1.60	−9.04**	0.51	0.45	0.00**
	BBB	0.14	-0.94	−2.22**	-0.58	0.42	0.00**
	BBB-	-0.25	-1.01	−2.22**	-1.08	0.33	0.03**
Baa Corporate Spread	AAA	1.58	−5.89**	−5.12**	1.54	0.53	0.00**
	AA	-0.13	−2.58**	−4.07**	1.22	0.52	0.00**
	A	0.72	−2.48**	−4.67**	-0.70	0.54	0.00**
	BBB	-0.31	-0.96	−2.28**	-1.28	0.45	0.00**
	BBB-	-0.54	-1.12	−2.43**	−2.56**	0.40	0.01**
S&P 500 Subindex	AAA	1.09	1.55	0.37	-0.48	0.36	0.41
	AA	1.91*	−2.13**	2.87**	-0.10	0.47	0.02**
	A	2.43**	-0.34	2.39**	0.46	0.51	0.01**
	BBB	1.77*	0.92	1.68*	1.29	0.50	0.01**
	BBB-	3.24**	0.76	2.08**	1.73*	0.52	0.00**
S&P 500 Index	AAA	2.08**	2.84**	0.20	-0.40	0.29	0.09*
	AA	1.28	0.91	2.92**	0.23	0.30	0.09*
	A	1.35	0.78	3.11**	1.25	0.36	0.01**
	BBB	0.58	1.34	1.96*	2.68**	0.44	0.00**
	BBB-	1.92*	0.76	2.18**	3.19**	0.41	0.00**
VIX Index	AAA	−4.15**	−2.85**	1.55	0.46	0.34	0.05*
	AA	−2.27**	-0.90	-0.93	0.31	0.34	0.05*
	A	−3.97**	-1.42	−3.76**	-0.61	0.44	0.00**
	BBB	−1.82*	−2.59**	−2.82**	−2.09**	0.52	0.00**
	BBB-	−2.67**	-1.63	−2.89**	−2.82**	0.49	0.00**

Table 5.6: Spliced ABX Index 2008 VAR Estimation Results

Notes: This table reports results from the following VAR estimation:

$$y_t = \alpha + \sum_{k=1}^{4} \beta_k Y_{t-k} + \gamma_k ABX_{t-k} + \epsilon_t,$$

in which y_t denotes the financial market measure included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. ABX_{t-k} denotes the ABX asset included as an exogenous variable. As there are five ratings classes there are five ABX assets in each ABX series and so the VAR system is estimated for each of these. Four lags are suggested by the Akaike Information Criterion (AIC). Reported are Newey-West adjusted t-statistics, R^2s and p-values of the F-test that the γ coefficients are jointly zero. T-statistics are reported in parentheses. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Y	ABX	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	AAA	-1.35	0.15	1.29	2.31**	0.12	0.43
	AA	-1.46	1.04	0.21	-0.04	0.09	0.64
	A	-1.09	1.21	-1.29	0.90	0.10	0.58
	BBB	−2.71**	0.40	-0.19	-0.14	0.11	0.51
	BBB-	−2.56**	-0.10	-0.06	-1.00	0.12	0.44
10-Year T-bill	AAA	-0.51	2.30**	0.62	0.57	0.23	0.19
	AA	0.80	2.69**	-0.72	-0.33	0.26	0.09*
	A	0.46	1.53	-1.24	0.74	0.19	0.36
	BBB	-0.43	1.06	-0.41	0.33	0.13	0.86
	BBB-	-0.58	1.33	-0.82	-0.05	0.16	0.66
Aaa Corporate Spread	AAA	-0.63	-0.88	-0.31	0.81	0.22	0.78
	AA	-0.27	0.44	1.09	0.59	0.20	0.89
	A	-0.42	0.56	1.35	0.10	0.21	0.86
	BBB	0.38	1.38	1.39	0.22	0.22	0.72
	BBB-	0.41	2.00**	1.39	1.13	0.24	0.57
Baa Corporate Spread	AAA	-0.02	-0.62	1.40	1.07	0.23	0.53
	AA	0.07	0.17	1.42	1.05	0.22	0.63
	A	0.00	0.19	1.63	0.34	0.21	0.72
	BBB	1.09	1.50	1.08	0.17	0.24	0.47
	BBB-	0.91	1.71*	1.08	1.11	0.23	0.47
S&P 500 Subindex	AAA	-0.90	-0.14	0.45	-0.66	0.14	0.88
	AA	-0.02	0.16	-1.58	-1.29	0.16	0.73
	A	0.57	-0.88	−3.01**	-0.93	0.24	0.19
	BBB	-0.25	-1.16	0.41	-0.54	0.16	0.85
	BBB-	-0.39	-0.90	0.30	-1.00	0.15	0.82
S&P 500 Index	AAA	−2.19**	0.15	0.46	-1.47	0.25	0.06*
	AA	−1.89*	0.75	−2.01**	-0.87	0.25	0.07*
	A	-1.41	0.37	−2.95**	-0.36	0.21	0.17
	BBB	−1.74*	-0.05	-0.99	-0.68	0.21	0.15
	BBB-	−1.81*	-0.23	-1.26	-0.60	0.21	0.16
VIX Index	AAA	2.07**	0.20	0.90	0.22	0.18	0.22
	AA	2.70**	-1.38	2.53**	0.03	0.29	0.02**
	A	2.39**	-0.64	1.84**	0.65	0.16	0.32
	BBB	1.50	0.58	0.55	0.72	0.19	0.21
	BBB-	1.28	0.79	0.53	0.79	0.15	0.39

Table 5.7: Spliced ABX Index 2009 VAR Estimation Results

Notes: This table reports results from the following VAR estimation:

$$y_t = \alpha + \sum_{k=1}^{4} \beta_k Y_{t-k} + \gamma_k ABX_{t-k} + \epsilon_t,$$

in which y_t denotes the financial market measure included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. ABX_{t-k} denotes the ABX asset included as an exogenous variable. As there are five ratings classes there are five ABX assets in each ABX series and so the VAR system is estimated for each of these. Four lags are suggested by the Akaike Information Criterion (AIC). Reported are Newey-West adjusted t-statistics, R^2s and p-values of the F-test that the γ coefficients are jointly zero. T-statistics are reported in parentheses. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Y	ABX	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	AAA	-1.23	1.20	0.53	0.20	0.18	0.40
	AA	0.85	-1.04	1.39	-0.47	0.19	0.27
	A	0.04	0.28	1.35	-1.23	0.23	0.68
	BBB	-0.45	-0.80	1.34	0.63	0.17	0.19
	BBB-	-0.53	-1.04	1.54	0.43	0.19	0.09*
10-Year T-bill	AAA	0.89	0.23	-0.27	0.98	0.18	0.86
	AA	1.42	-1.62	-0.06	-1.07	0.20	0.06*
	A	1.82*	-1.01	0.49	−1.84*	0.26	0.18
	BBB	-0.18	-1.48	1.20	0.50	0.16	0.08*
	BBB-	-0.33	-1.50	1.31	-0.17	0.19	0.00**
Aaa Corporate Spread	AAA	-1.11	-0.43	0.42	-0.72	0.28	0.67
	AA	-0.95	0.51	0.00	−2.08**	0.31	0.02**
	A	-1.01	0.15	-0.83	1.59	0.30	0.47
	BBB	0.82	-0.20	−1.82*	-0.29	0.27	0.00**
	BBB-	0.52	-0.03	−1.77*	0.08	0.26	0.03**
Baa Corporate Spread	AAA	-1.44	-0.23	-0.07	-1.37	0.17	0.58
	AA	-0.74	0.92	-0.71	2.75**	0.16	0.01**
	A	-0.52	0.33	-1.55	1.63	0.18	0.27
	BBB	0.60	-0.33	-1.53	-0.09	0.13	0.04**
	BBB-	0.46	-0.13	-1.48	0.22	0.13	0.05*
S&P 500 Subindex	AAA	0.43	-1.01	-0.51	-0.92	0.11	0.24
	AA	1.24	−2.81**	-1.46	-0.10	0.20	0.00**
	A	0.69	-0.74	0.37	−2.32**	0.17	0.14
	BBB	0.41	-0.95	-1.56	-0.55	0.12	0.24
	BBB-	0.16	-0.97	-0.21	−1.68*	0.12	0.13
S&P 500 Index	AAA	0.67	-0.38	-0.55	-0.94	0.04	0.46
	AA	1.34	−3.29**	-0.17	-0.86	0.12	0.00**
	A	1.47	-0.15	0.44	−1.95*	0.12	0.23
	BBB	1.20	-0.82	−1.67*	-0.42	0.05	0.26
	BBB-	0.67	-0.40	-0.57	-1.25	0.04	0.15
VIX Index	AAA	-1.63	-0.28	0.61	2.15**	0.37	0.08*
	AA	-1.08	1.22	0.55	1.38	0.34	0.19
	A	-0.36	0.68	-1.03	0.93	0.33	0.37
	BBB	−2.53**	-0.39	0.93	0.75	0.35	0.05*
	BBB-	−2.36**	-0.37	0.30	1.26	0.34	0.05*

Table 5.8: ABX 06-1 Vintage 2006 VAR Estimation Results

Notes: This table reports results from the following VAR estimation:

$$y_t = \alpha + \sum_{k=1}^{4} \beta_k Y_{t-k} + \gamma_k ABX_{t-k} + \epsilon_t,$$

in which y_t denotes the financial market measure included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. ABX_{t-k} denotes the ABX asset included as an exogenous variable. As there are five ratings classes there are five ABX assets in each ABX series and so the VAR system is estimated for each of these. Four lags are suggested by the Akaike Information Criterion (AIC). Reported are Newey-West adjusted t-statistics, R^2s and p-values of the F-test that the γ coefficients are jointly zero. T-statistics are reported in parentheses. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Y	ABX	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	AAA	-1.56	0.78	0.33	0.63	0.08	0.38
	AA	0.40	0.98	-0.29	0.88	0.07	0.45
	A	-1.23	0.61	-1.54	-0.61	0.12	0.55
	BBB	-1.04	0.35	-0.71	-0.49	0.09	0.76
	BBB-	-0.72	1.40	-1.14	-0.23	0.09	0.43
10-Year T-bill	AAA	-0.21	0.78	1.17	1.86	0.10	0.22
	AA	2.22**	3.03**	0.72	0.99	0.16	0.01**
	A	-0.20	0.59	-1.13	-0.52	0.07	0.64
	BBB	-0.25	-0.08	-0.73	0.26	0.06	0.87
	BBB-	0.09	1.06	-1.23	0.41	0.08	0.69
Aaa Corporate Spread	AAA	-0.72	0.27	0.23	-1.47	0.36	0.44
	AA	-0.79	-0.46	1.48	-0.10	0.37	0.53
	A	0.45	0.93	3.19**	0.81	0.40	0.02**
	BBB	0.56	1.30	1.51	-0.34	0.39	0.27
	BBB-	0.93	0.61	2.26**	-0.05	0.41	0.05*
Baa Corporate Spread	AAA	-0.79	-0.39	-1.20	−2.47**	0.47	0.00**
	AA	-0.87	-1.23	0.99	-0.66	0.45	0.39
	A	-0.14	-0.54	1.43	0.27	0.43	0.42
	BBB	0.23	0.18	1.07	-0.90	0.43	0.62
	BBB-	0.33	-0.71	1.28	-1.23	0.43	0.43
S&P 500 Subindex	AAA	-0.15	2.26**	-1.63	-0.34	0.22	0.12
	AA	−2.12**	−1.86*	-0.40	-0.63	0.25	0.00**
	A	−2.39**	−2.41**	-1.18	-0.95	0.37	0.07*
	BBB	−2.78**	-1.61	-1.54	0.95	0.29	0.01**
	BBB-	−1.93*	-1.13	0.02	-0.17	0.23	0.11
S&P 500 Index	AAA	-0.95	1.66*	-1.46	0.44	0.22	0.54
	AA	-1.51	-1.54	-0.73	0.08	0.22	0.16
	A	−2.23**	−2.58**	−2.61**	-0.76	0.40	0.05*
	BBB	-1.40	-1.36	-0.94	1.27	0.26	0.34
	BBB-	-1.54	-0.71	-0.03	0.37	0.20	0.41
VIX Index	AAA	1.64	−1.81*	-0.34	-0.58	0.16	0.07*
	AA	0.74	0.28	0.49	-0.16	0.10	0.96
	A	1.66*	1.52	0.87	1.30	0.25	0.31
	BBB	1.36	0.26	-0.79	-0.62	0.14	0.34
	BBB-	1.64	-0.15	-1.23	0.61	0.13	0.00**

Table 5.9: ABX 06-1 Vintage 2007 VAR Estimation Results

Notes: This table reports results from the following VAR estimation:

$$y_t = \alpha + \sum_{k=1}^{4} \beta_k Y_{t-k} + \gamma_k ABX_{t-k} + \epsilon_t,$$

in which y_t denotes the financial market measure included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. ABX_{t-k} denotes the ABX asset included as an exogenous variable. As there are five ratings classes there are five ABX assets in each ABX series and so the VAR system is estimated for each of these. Four lags are suggested by the Akaike Information Criterion (AIC). Reported are Newey-West adjusted t-statistics, R^2s and p-values of the F-test that the γ coefficients are jointly zero. T-statistics are reported in parentheses. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Y	ABX	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	AAA	2.00**	3.89**	3.07**	0.65	0.33	0.00**
	AA	3.27**	2.83**	2.25**	0.01	0.44	0.00**
	A	2.57**	1.72*	3.66**	-0.05	0.49	0.00**
	BBB	1.83*	1.18	3.59**	1.23	0.42	0.00**
	BBB-	1.74*	0.39	4.59**	2.06**	0.43	0.00**
10-Year T-bill	AAA	1.78*	4.53**	1.48	0.76	0.23	0.00**
	AA	0.47	4.32**	1.95*	2.16**	0.25	0.00**
	A	2.65**	1.73*	6.77**	1.18	0.34	0.00**
	BBB	3.34**	2.88**	5.91**	2.67**	0.40	0.00**
	BBB-	4.23**	1.82*	4.94**	4.11**	0.42	0.00**
Aaa Corporate Spread	AAA	-0.96	−2.06**	-0.81	−2.04**	0.19	0.00**
	A	3.34**	2.88**	5.91**	2.67**	0.40	0.02**
	AA	-0.77	−2.31**	−2.10**	−3.57**	0.24	0.00**
	A	-1.47	0.18	−3.71**	−1.85*	0.25	0.00**
	BBB	−1.86*	0.06	−2.00**	−2.98**	0.21	0.02**
	BBB-	−2.06**	0.30	−1.67*	−3.08**	0.22	0.01**
Baa Corporate Spread	AAA	−2.77**	−3.45**	−2.74**	−5.36**	0.40	0.00**
	AA	−3.18**	−6.76**	−2.72**	−6.89**	0.43	0.00**
	A	−2.62**	-0.37	−5.50**	−3.83**	0.48	0.00**
	BBB	−3.51**	-0.08	−5.04**	−6.71**	0.44	0.00**
	BBB-	−3.33**	0.12	−3.25**	−7.14**	0.44	0.00**
S&P 500 Subindex	AAA	1.60	-0.79	-0.86	1.82*	0.37	0.02**
	AA	2.27**	-1.26	0.93	1.65*	0.39	0.00**
	A	3.04**	-1.54	4.32**	-0.04	0.48	0.00**
	BBB	3.41**	-1.10	3.08**	1.17	0.44	0.00**
	BBB-	3.21**	-0.13	1.96*	2.56**	0.43	0.00**
S&P 500 Index	AAA	1.44	0.60	-0.52	1.32	0.25	0.54
	AA	1.92*	1.34	1.47	1.85*	0.27	0.00**
	A	3.38**	-0.14	4.64**	0.85	0.38	0.00**
	BBB	2.22**	-0.50	3.27**	3.16**	0.32	0.00**
	BBB-	2.76**	0.19	2.04**	3.70**	0.31	0.00**
VIX Index	AAA	-1.50	-0.79	0.23	-0.60	0.20	0.47
	AA	−1.97*	−2.33**	−2.33**	-1.29	0.25	0.01**
	A	−3.85**	-0.56	−4.55**	-0.03	0.35	0.00**
	BBB	−2.47**	0.23	−2.79**	-0.62	0.30	0.05*
	BBB-	−2.08**	-1.25	−2.01**	-1.64	0.25	0.05*

Table 5.10: ABX 06-1 Vintage 2008 VAR Estimation Results

Notes: This table reports results from the following VAR estimation:

$$y_t = \alpha + \sum_{k=1}^{4} \beta_k Y_{t-k} + \gamma_k ABX_{t-k} + \epsilon_t,$$

in which y_t denotes the financial market measure included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. ABX_{t-k} denotes the ABX asset included as an exogenous variable. As there are five ratings classes there are five ABX assets in each ABX series and so the VAR system is estimated for each of these. Four lags are suggested by the Akaike Information Criterion (AIC). Reported are Newey-West adjusted t-statistics, R^2s and p-values of the F-test that the γ coefficients are jointly zero. T-statistics are reported in parentheses. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Y	ABX	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	AAA	0.48	0.76	2.53**	2.28**	0.13	0.03**
	AA	-0.09	0.24	2.31**	2.10**	0.16	0.02**
	A	-0.05	-0.06	0.45	2.45**	0.13	0.06*
	BBB	-0.00	0.94	0.53	0.02	0.09	0.73
	BBB-	0.03	-0.77	0.99	0.69	0.10	0.05*
10-Year T-bill	AAA	0.47	2.27**	1.21	1.26	0.27	0.00**
	AA	0.92	3.08**	0.65	1.47	0.32	0.00**
	A	0.81	1.78*	-0.89	2.00**	0.22	0.22
	BBB	1.34	1.78*	−1.77*	0.64	0.28	0.19
	BBB-	0.89	1.63	-1.13	0.97	0.23	0.26
Aaa Corporate Spread	AAA	-0.05	−2.94**	0.86	0.57	0.40	0.00**
	AA	-0.76	−2.14**	2.89**	0.64	0.43	0.05*
	A	-0.35	-1.03	2.81**	0.11	0.38	0.07*
	BBB	-0.64	-1.27	1.87*	0.25	0.40	0.40
	BBB-	-0.11	-0.92	1.45	0.02	0.37	0.60
Baa Corporate Spread	AAA	-0.45	−4.66**	1.39	1.00	0.30	0.00**
	AA	-0.80	−1.98*	3.33**	1.02	0.33	0.01**
	A	-0.09	-1.02	3.04**	0.32	0.28	0.02**
	BBB	-0.40	-1.24	1.71*	0.41	0.26	0.33
	BBB-	0.60	-1.26	1.41	0.48	0.24	0.50
S&P 500 Subindex	AAA	−2.42**	0.03	-1.27	−1.73*	0.21	0.05*
	AA	-1.24	0.17	-1.48	-1.06	0.15	0.15
	A	-0.16	-0.46	-1.50	0.45	0.10	0.44
	BBB	1.22	-0.86	-1.56	0.28	0.12	0.27
	BBB-	1.16	-1.52	-1.28	-0.06	0.13	0.15
S&P 500 Index	AAA	−3.80**	0.75	0.06	−2.13**	0.32	0.00**
	AA	−2.02**	0.80	-0.25	-1.21	0.24	0.14
	A	-1.02	-0.04	-1.09	0.28	0.13	0.65
	BBB	-0.23	0.25	-1.62	0.48	0.12	0.53
	BBB-	-0.64	-0.38	-0.93	-0.10	0.12	0.75
VIX Index	AAA	1.86*	-0.87	0.85	1.10	0.12	0.00**
	AA	1.63	0.09	1.14	-0.24	0.13	0.10
	A	1.35	-0.51	0.94	-0.80	0.10	0.61
	BBB	-0.57	-0.06	1.24	-0.86	0.08	0.61
	BBB-	-0.12	0.63	0.55	-0.19	0.06	0.85

Table 5.11: ABX 06-1 Vintage 2009 VAR Estimation Results

Notes: This table reports results from the following VAR estimation:

$$y_t = \alpha + \sum_{k=1}^{4} \beta_k Y_{t-k} + \gamma_k ABX_{t-k} + \epsilon_t,$$

in which y_t denotes the financial market measure included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. ABX_{t-k} denotes the ABX asset included as an exogenous variable. As there are five ratings classes there are five ABX assets in each ABX series and so the VAR system is estimated for each of these. Four lags are suggested by the Akaike Information Criterion (AIC). Reported are Newey-West adjusted t-statistics, R^2s and p-values of the F-test that the γ coefficients are jointly zero. T-statistics are reported in parentheses. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Y	ABX	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	AAA	1.48	0.13	-0.44	0.25	0.16	0.31
	AA	0.80	-1.40	0.27	0.79	0.19	0.49
	A	1.11	-2.25^{**}	-0.43	0.19	0.21	0.03^{**}
	BBB	1.92^{*}	0.65	-0.44	-0.91	0.20	0.28
	BBB-	0.91	-0.44	-0.47	-0.86	0.17	0.70
10-Year T-bill	AAA	-1.72^{*}	1.04	1.71^{*}	0.92	0.26	0.03^{**}
	AA	-1.58	1.13	1.92^{*}	-0.39	0.32	0.01^{**}
	A	-1.01	0.61	0.85	-0.74	0.18	0.12
	BBB	1.26	0.07	-0.25	-1.44	0.17	0.50
	BBB-	1.95^{*}	0.13	-1.23	2.62^{**}	0.19	0.06^{*}
Aaa Corporate Spread	AAA	-0.86	-2.56^{**}	-1.61	-1.63	0.36	0.00^{**}
	AA	-0.21	-2.07^{**}	-1.94^{*}	0.23	0.35	0.02^{**}
	A	0.14	-2.71^{**}	-0.29	1.76^{*}	0.29	0.01^{**}
	BBB	-1.90^{*}	-2.10^{**}	0.88	3.32^{**}	0.33	0.01^{**}
	BBB-	-3.07^{**}	-1.78^{*}	2.68^{**}	5.22^{**}	0.36	0.00^{**}
Baa Corporate Spread	AAA	0.35	-2.05^{**}	-1.56	-1.19	0.22	0.00^{**}
	AA	0.40	-1.97^{*}	-1.90^{*}	0.17	0.22	0.00^{**}
	A	0.20	-2.98^{**}	-0.31	1.66^{*}	0.17	0.00^{**}
	BBB	-1.94^{*}	-3.20^{**}	1.08	2.81^{**}	0.22	0.01^{**}
	BBB-	-2.72^{**}	-1.74^{*}	2.02^{**}	2.57^{**}	0.21	0.00^{**}
S&P 500 Subindex	AAA	-0.76	0.04	0.39	-1.75^{*}	0.13	0.02^{**}
	AA	-2.80^{**}	0.44	0.22	-0.74	0.14	0.05^{*}
	A	-2.31^{**}	-0.40	0.23	0.28	0.19	0.02^{**}
	BBB	-2.33^{**}	-1.75^{*}	0.49	0.06	0.19	0.02^{**}
	BBB-	-1.24	0.98	0.33	-1.05	0.15	0.49
S&P 500 Index	AAA	-0.27	0.96	0.26	-0.89	0.04	0.12
	AA	-2.66^{**}	1.37	0.37	0.50	0.09	0.01^{**}
	A	-2.88^{**}	-0.39	0.88	1.11	0.12	0.00^{**}
	BBB	-1.22	-1.38	-0.15	0.27	0.05	0.19
	BBB-	0.01	0.91	-0.15	-0.53	0.02	0.84
VIX Index	AAA	-0.42	-0.09	-0.48	0.76	0.30	0.82
	AA	0.22	-0.36	-0.08	0.48	0.30	0.96
	A	1.62	1.46	1.18	-0.65	0.41	0.00^{**}
	BBB	-2.16^{**}	1.35	1.65^{*}	1.58	0.37	0.08^{*}
	BBB-	-1.60	0.37	0.90	1.14	0.32	0.35

Table 5.12: ABX 06-2 Vintage VAR Estimation Results

Notes: This table reports results from the following VAR estimation:

$$Y_t = \alpha_0 + \sum_{k=1}^{2} \beta_k Y_{t-k} + \sum_{k=1}^{2} \gamma_k ABX_{t-k},$$
$$+\delta_0 D1 + \sum_{k=1}^{2} D1(\beta_k - \lambda_k) Y_{t-k} + \sum_{k=1}^{2} D1(\gamma_k - \upsilon_k) ABX_{t-k},$$
$$+\theta_0 D2 + \sum_{k=1}^{2} D2(\beta_k - \delta_k) Y_{t-k} + \sum_{k=1}^{2} D2(\gamma_k - \eta_k) ABX_{t-k},$$
$$+\phi_0 D3 + \sum_{k=1}^{2} D3(\beta_k - \psi_k) Y_{t-k} + \sum_{k=1}^{2} D3(\gamma_k - \tau_k) ABX_{t-k},$$
$$+\epsilon_t,$$

in which α_0 denotes the 2006 constant term, $\delta_0 D1$ denotes the 2007 constant term, $\theta_0 D2$ denotes the 2008 constant term, $\phi_0 D3$ denotes the 2009 constant term, Y_t denotes the financial market variable included as a dependent variable, ABX_{t-k} denotes the ABX ratings tranche included as a dependent variable. Two lags are determined by the Akaike Information Criterion. Reported are the p-values of the F-test that the indicated coefficients are jointly zero. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

	Dependent						
Regressor	One-yrTbill	10-yrTbill	AaaSprd	BaaSprd	S&P500	S&PSub	VIX
AAA_{2006}	0.00**	0.00**	0.00**	0.01**	0.00**	0.00**	0.03**
AA_{2006}	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**
A_{2006}	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**
BBB_{2006}	0.03**	0.03**	0.00**	0.00**	0.00**	0.00**	0.84
$BBB-_{2006}$	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.91
AAA_{2007}	0.00**	0.00**	0.00**	0.00**	0.89	0.02**	0.21
AA_{2007}	0.00**	0.00**	0.00**	0.00**	0.87	0.00**	0.53
A_{2007}	0.00**	0.00**	0.00**	0.05**	0.60	0.00**	0.73
BBB_{2007}	0.05*	0.02**	0.00**	0.01**	0.61	0.00**	0.05**
$BBB-_{2007}$	0.01**	0.00**	0.00**	0.00**	0.57	0.00**	0.04**
AAA_{2008}	0.00**	0.00**	0.01**	0.00**	0.00**	0.06*	0.06*
AA_{2008}	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.60
A_{2008}	0.00**	0.00**	0.00**	0.00**	0.03**	0.00**	0.69
BBB_{2008}	0.02**	0.01**	0.00**	0.00**	0.00**	0.01**	0.20
$BBB-_{2008}$	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.19
AAA_{2009}	0.00**	0.00**	0.00**	0.01**	0.37	0.09*	0.00**
AA_{2009}	0.00**	0.00**	0.00**	0.00**	0.32	0.02**	0.00**
A_{2009}	0.00**	0.00**	0.00**	0.00**	0.19	0.01**	0.00**
BBB_{2009}	0.00**	0.00**	0.01**	0.00**	0.25	0.07*	0.69
$BBB-_{2009}$	0.00**	0.00**	0.00**	0.00**	0.22	0.04**	0.13

Table 5.13: Spliced ABX Index VAR Estimation Results 2

Notes: This table reports results from the following VAR estimation:

$$y_t = \alpha + \sum_{k=1}^{4} \beta_k Y_{t-k} + \gamma_k PC_{1,t-k} + \epsilon_t,$$

in which y_t denotes the financial market measure included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. $PC_{1,t-k}$ denotes that principal component one is included as an exogenous variable. Four lags are suggested by the Akaike Information Criterion (AIC). Reported are Newey-West adjusted t-statistics, R^2s and p-values of the F-test that the γ coefficients are jointly zero. T-statistics are reported in parentheses. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

				2006			
Y	X	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	PC_1	-0.92	0.93	-0.61	-0.37	0.68	0.46
10-Year T-bill	PC_1	-0.64	0.63	-1.56	0.44	0.08	0.23
Aaa Corporate Spread	PC_1	1.80*	1.58	2.39**	-0.40	0.43	0.00**
Baa Corporate Spread	PC_1	1.47	0.40	1.77*	-1.22	0.45	0.01**
S&P 500 Subindex	PC_1	-1.51	-1.55	-1.43	0.74	0.25	0.01**
S&P 500 Index	PC_1	-1.00	-1.47	-0.63	0.92	0.21	0.53
VIX Index	PC_1	1.84*	-0.25	-0.93	0.28	0.12	0.04**
				2007			
Y	X	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	PC_1	-0.28	-0.52	−7.24**	−1.85*	0.49	0.00**
10-Year T-bill	PC_1	-1.23	-0.55	−3.83**	−2.13**	0.35	0.00**
Aaa Corporate Spread	PC_1	0.22	-0.22	2.55**	1.78*	0.22	0.01**
Baa Corporate Spread	PC_1	0.01	-0.85	5.37**	4.22**	0.47	0.00**
S&P 500 Subindex	PC_1	−2.48**	-0.35	−2.62**	-1.60	0.49	0.00**
S&P 500 Index	PC_1	-1.31	-1.12	−2.82**	−2.07**	0.41	0.00**
VIX Index	PC_1	2.87**	−2.09**	-0.15	−2.75**	0.24	0.01**
				2008			
Y	X	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	PC_1	-0.77	-0.99	0.76	1.47	0.13	0.48
10-Year T-bill	PC_1	0.35	-0.89	−1.67*	3.01**	0.26	0.05*
Aaa Corporate Spread	PC_1	−2.64**	-0.59	0.87	−5.37**	0.52	0.00**
Baa Corporate Spread	PC_1	−2.45**	-0.90	0.28	−4.17**	0.37	0.00**
S&P 500 Subindex	PC_1	1.39	1.12	-0.48	1.78*	0.17	0.44
S&P 500 Index	PC_1	1.58	0.69	-0.09	1.96*	0.21	0.27
VIX Index	PC_1	-1.16	0.62	-1.16	−2.71**	0.15	0.06*
				2009			
Y	X	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	PC_1	1.25	-1.15	-1.09	-0.08	0.18	0.35
10-Year T-bill	PC_1	-1.03	0.33	0.26	-0.28	0.18	0.89
Aaa Corporate Spread	PC_1	1.21	0.14	-0.44	-0.03	0.27	0.45
Baa Corporate Spread	PC_1	1.38	-0.17	0.16	0.62	0.15	0.66
S&P 500 Subindex	PC_1	-0.68	1.43	0.42	1.24	0.14	0.03**
S&P 500 Index	PC_1	-1.01	0.70	0.39	1.29	0.07	0.17
VIX Index	PC_1	2.10**	0.16	-0.44	−2.36**	0.39	0.05*

Table 5.14: ABX 06-1 Vintage VAR Estimation Results 2

Notes: This table reports results from the following VAR estimation:

$$y_t = \alpha + \sum_{k=1}^{4} \beta_k Y_{t-k} + \gamma_k PC_{1,t-k} + \epsilon_t,$$

in which y_t denotes the financial market measure included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. $PC_{1,t-k}$ denotes that principal component one is included as an exogenous variable. Four lags are suggested by the Akaike Information Criterion (AIC). Reported are Newey-West adjusted t-statistics, R^2s and p-values of the F-test that the γ coefficients are jointly zero. T-statistics are reported in parentheses. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

				2006			
Y	X	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	PC_1	-0.81	1.08	-1.01	-0.33	0.09	0.60
10-Year T-bill	PC_1	-0.01	0.84	-1.06	0.36	0.07	0.76
Aaa Corporate Spread	PC_1	0.80	0.84	2.14**	-0.08	0.41	0.09*
Baa Corporate Spread	PC_1	0.26	-0.53	1.25	-1.14	0.43	0.43
S&P 500 Subindex	PC_1	−2.32**	-1.27	-0.44	0.24	0.25	0.04**
S&P 500 Index	PC_1	-1.61	-0.90	-0.31	0.68	0.22	0.39
VIX Index	PC_1	1.62	-0.04	-1.01	0.24	0.13	0.03**
				2007			
Y	X	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	PC_1	−2.01**	-1.01	−3.83**	-1.23	0.46	0.00**
10-Year T-bill	PC_1	−3.31**	−2.35**	−6.02**	−2.74**	0.39	0.00**
Aaa Corporate Spread	PC_1	1.75*	-0.20	2.11**	3.02**	0.23	0.01**
Baa Corporate Spread	PC_1	3.07**	0.05	4.47**	7.13**	0.46	0.00**
S&P 500 Subindex	PC_1	−3.85**	1.02	−3.30**	-1.63	0.46	0.00**
S&P 500 Index	PC_1	−2.47**	0.18	−3.19**	−3.38**	0.34	0.00**
VIX Index	PC_1	2.64**	0.50	2.91**	0.88	0.30	0.03**
				2008			
Y	X	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	PC_1	-0.06	0.07	-0.89	-1.24	0.11	0.44
10-Year T-bill	PC_1	-0.87	−2.10**	1.57	-1.57	0.28	0.03**
Aaa Corporate Spread	PC_1	0.32	1.66*	−2.99**	-0.01	0.40	0.03**
Baa Corporate Spread	PC_1	0.03	1.86*	−3.23**	-0.40	0.29	0.01**
S&P 500 Subindex	PC_1	-0.21	0.63	2.08**	-0.14	0.11	0.32
S&P 500 Index	PC_1	1.05	-0.75	1.33	0.08	0.14	0.56
VIX Index	PC_1	-0.81	0.36	-1.09	0.56	0.08	0.83
				2009			
Y	X	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	PC_1	-1.19	1.42	-0.13	-0.65	0.19	0.46
10-Year T-bill	PC_1	1.60	-0.98	−1.77*	0.53	0.31	0.00**
Aaa Corporate Spread	PC_1	0.23	2.42**	1.59	-0.43	0.34	0.01**
Baa Corporate Spread	PC_1	-0.31	2.30**	1.55	-0.38	0.21	0.00**
S&P 500 Subindex	PC_1	3.25**	-0.34	-0.30	0.83	0.16	0.01**
S&P 500 Index	PC_1	2.87**	-1.12	-0.40	-0.39	0.10	0.00**
VIX Index	PC_1	-0.31	-0.04	-0.06	-0.38	0.29	0.98

Table 5.15: ABX 06-2 Vintage VAR Estimation Results 2

Notes: This table reports results from the following VAR estimation:

$$y_t = \alpha + \sum_{k=1}^{4} \beta_k Y_{t-k} + \gamma_k PC1_{t-k} + \epsilon_t,$$

in which y_t denotes the financial market measure included as the dependent variable. Thus, there are seven dependent variables and the system is estimated separately for each one. $PC1_{t-k}$ denotes that principal component one is included as an exogenous variable. Four lags are suggested by the Akaike Information Criterion (AIC). Reported are Newey-West adjusted t-statistics, R^2s and p-values of the F-test that the γ coefficients are jointly zero. T-statistics are reported in parentheses. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Y	X	γ_1	γ_2	γ_3	γ_4	R^2	p
2006							
One-Year T-bill	PC_1	1.23	1.78*	-0.38	2.02**	0.36	0.32
10-Year T-bill	PC_1	0.90	0.70	−3.41**	−2.42**	0.58	0.00**
Aaa Corporate Spread	PC_1	2.88**	1.92*	2.50**	0.13	0.71	0.00**
Baa Corporate Spread	PC_1	2.97**	1.10	2.05**	-0.42	0.73	0.00**
S&P 500 Subindex	PC_1	0.05	-1.59	-0.22	0.03	0.24	0.00**
S&P 500 Index	PC_1	2.99**	-0.84	2.28**	0.76	0.55	0.00**
VIX Index	PC_1	-0.13	-1.04	−2.72**	-0.43	0.71	0.00**
2007							
Y	X	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	PC_1	-0.48	0.19	−5.29**	−1.65*	0.52	0.00**
10-Year T-bill	PC_1	-1.39	-0.52	−6.35**	−2.02**	0.43	0.00**
Aaa Corporate Spread	PC_1	0.59	-0.58	3.44**	1.48	0.24	0.00**
Baa Corporate Spread	PC_1	0.68	-1.31	5.05**	3.81**	0.47	0.00**
S&P 500 Subindex	PC_1	−3.10**	-0.03	−3.39**	−2.00**	0.49	0.00**
S&P 500 Index	PC_1	−1.71*	-0.67	−3.02**	−1.82*	0.38	0.00**
VIX Index	PC_1	2.38**	1.48	2.32**	0.69	0.37	0.00**
2008							
Y	X	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	PC_1	0.45	0.53	-1.14	-1.02	0.12	0.38
10-Year T-bill	PC_1	-0.69	−1.76*	0.90	-1.36	0.22	0.21
Aaa Corporate Spread	PC_1	0.16	1.08	−1.90*	-0.16	0.37	0.32
Baa Corporate Spread	PC_1	-0.16	0.99	−2.26**	-0.70	0.28	0.14
S&P 500 Subindex	PC_1	0.22	0.94	1.25	-0.07	0.11	0.74
S&P 500 Index	PC_1	1.29	0.09	1.01	0.21	0.17	0.58
VIX Index	PC_1	-1.08	-0.09	-0.77	0.45	0.10	0.79
2009							
Y	X	γ_1	γ_2	γ_3	γ_4	R^2	p
One-Year T-bill	PC_1	0.79	2.09**	−3.60**	1.71*	0.35	0.01**
10-Year T-bill	PC_1	0.58	-0.18	−2.75**	2.89**	0.30	0.02**
Aaa Corporate Spread	PC_1	-0.90	1.99*	1.96*	−3.95**	0.39	0.00**
Baa Corporate Spread	PC_1	-0.45	1.52	1.89*	−4.38**	0.25	0.00**
S&P 500 Subindex	PC_1	1.51	0.68	-0.91	1.66*	0.14	0.03**
S&P 500 Index	PC_1	0.86	0.09	−1.77*	2.75**	0.11	0.10
VIX Index	PC_1	2.25**	-0.03	2.02**	−2.33**	0.38	0.01**

Chapter 6

A Regime Switching Analysis of Contagion from the U.S. Subprime Mortgage-Backed Securities Market

6.1. Introduction and Related Literature

This chapter addresses some of the methodological limitations of the original VAR analysis of Longstaff (2010), employed in Chapters 4 and 5, to test for contagion from the U.S. subprime mortgage-backed securities market to government, corporate, volatility and equity markets during the 2007-2009 financial crisis. As in Chapters 4 and 5 we adopt the definition of contagion presented by Forbes & Rigobon (2002) as "a significant increase in cross-market linkages after a shock occurs in one market". To extend the VAR framework of Longstaff (2010), a time-varying transition probability Markov-switching VAR (TVTP MS-VAR) model, developed by Filardo (1994), is employed. In the model both variances and coefficients are allowed to switch discretely between two regimes; a non-crisis regime characterized by low volatility and a crisis regime classified by high volatility. This framework allows regimes to be determined endogenously by the data, a feature not present in the original application employed by Longstaff (2010), in which regimes are imposed exogenously. It also enables the transition probability matrix for a switch in regime to be driven by an ABX asset, another aspect not present in the original methodology. We treat the ABX indexes as our possible source of contagion and are interested in analysing asset market interactions in low- and high-volatility regimes triggered by the subprime mortgage-backed securities market.

Regime switching approaches to testing for contagion were initially used primarily in business cycle research, as in Hamiliton (1989) and, in recent years, in currency crisis literature, such as in Mandilaras & Bird (2010). They argue the use of a regime switching methodology, highlighting such advantages as the fact that the endogenous choice of crisis and non-crisis periods eliminates the need to select regimes a priori. Analysing European exchange rates during the Exchange Rate Mechanism (ERM) they find that a Markov-switching VAR is an appropriate methodology as it successfully identifies the eleven realignments of the ERM. Using a multivariate version of the Forbes & Rigobon (2002) contagion test they find evidence of contagion in the European Monetary System (EMS). Billio et al. (2005) review Markov switching models in contagion analysis by analysing the 1997 Hong Kong stock market crash, treating contagion as a structural break in the data generating process during a crisis. They also point out that one advantage of Markov-switching models is the endogenous identification of crisis periods from sample data, along with the fact that such models can sufficiently handle theoretical issues such as nonlinearity.

Using a CDS index to represent the U.S. credit default market, Guo et al. (2011) test for cross-market contagion among this market, a U.S. stock market, real estate market, and energy market during the 2007 crisis using a Markov-switching vector autoregressive (MS-VAR) framework. They find that stock market and oil shocks are driving forces behind credit default market and stock market variations, respectively.

Markov-switching models with time-varying transition probabilities have been applied mainly in currency crises literature, such as Peria (2002), Brunetti et al. (2008) and Mouratidis (2008).

In this chapter we adopt a TVTP MS-VAR analysis, which is performed on both the spliced ABX index employed by Longstaff (2010) and a traded ABX vintage. We determine two regimes, a non-crisis regime characterized by low volatility and a crisis regime classified by high volatility. The watershed of regimes occurs in mid-2007, with the crisis regime dominating thereafter until the end of the sample, suggesting that imposing a crisis regime to begin in January 2007, as in Longstaff (2010), is not appropriate. Although we observe an increase in the correlation between the ABX asset and the majority of financial variables analysed when the regime switches from a non-crisis to a crisis state we do not observe any evidence of price discovery in the VAR coefficients and so we fail to reject the null hypothesis of no contagion from the ABX indexes analysed to the financial market variables during the crisis regime, a result in direct contrast to that presented by Longstaff (2010). This may be due to the timing of market events and the transmission of shocks through other channels, such as real estate and asset-backed commercial paper (ABCP) markets. The results also highlight differences between the spliced ABX index and the traded vintages, suggesting that analysis of the spliced ABX index alone may not provide an accurate depiction of what was happening in this market over the sample period and splicing the data may influence results.

A number of robustness checks are performed, including trivariate TVTP MS-VAR analyses. The results suggest some evidence of contagion from the ABX market to the other financial markets, although contagion is not as widespread as that reported in Longstaff (2010). This indicates that accurately timing the onset of the crisis is crucial, and the original application may have induced persistence due to employing four lags and ignoring the structural break that occurred in mid-2007.

The remainder of the chapter is organised as follows. Section 6.2 describes the data analysed while section 6.3 discusses the results of a rolling VAR analysis. Section 6.4 describes the time-varying transition probability Markov-switching VAR framework and specifies the model employed. Section 6.5 presents the results of a number of robustness checks. A final section then concludes.

6.2. Data

As mentioned earlier this chapter analyses the spliced ABX index and financial market variables analysed by Longstaff (2010), as well as one traded ABX vintage, the ABX 06-1. Chapter 2, section 2.3.1, describes the ABX indexes in detail and Chapter 4, section 4.3.1 describes the spliced ABX index. Longstaff (2010) analyses weekly returns of the five assets comprising the spliced ABX index to proxy for returns in the distressed subprime mortgage-backed CDO market. He tests for contagion from this market to several equity, volatility and fixed-income markets, described in Chapter 5, section 5.3.1. As we are estimating a highly nonlinear model we include one proxy for each financial market mentioned in an effort to reduce the number of coefficients to be estimated and yield more accurate results. We therefore include weekly percentage changes of the S&P 500 index, the VIX index and the Aaa-rated corporate spread. A Treasury bond spread is created by subtracting the short-term yield from the long-term yield. Weekly percentage changes of this spread are included to account for changes in the Treasury market. As with the ABX indexes the financial market variables data range from January 19, 2006, to December 31, 2009.

6.3. Rolling Vector Autoregressive Analysis

To test for contagion Longstaff (2010) divides the data into three distinct periods; a "pre-crisis" period for 2006, a "subprime-crisis" period for 2007 and a "global-crisis" period for 2008, therefore allowing the VAR coefficients to vary by year. This framework assumes that the system switches from a non-crisis to a "subprime-crisis" regime on January 1, 2007, and to a "global-crisis" regime on January 1, 2008. If this is a reasonable assumption we should observe a change in coefficient behaviour at these times. Therefore, as a preliminary analysis of the stability of the coefficients in the VAR system, a rolling VAR is estimated with a window width of 24. This window width is chosen as there are relatively few observations in the data sets analysed.[1] The VAR specification estimated is as follows:

$$Y_t = \alpha + \sum_{k=1}^{4}(\beta_k Y_{t-k} + \gamma_k ABX_{t-k}) + \epsilon_t, \tag{6.1}$$

in which Y_t denotes the financial market measure included as the dependent variable. Thus, there are four dependent variables and the system is estimated separately for each one. ABX_{t-k} denotes the ABX asset included as an exogenous variable. As there are five ratings classes there are five ABX assets in each ABX series and so the VAR system is estimated for each of these. Four lags are suggested by the Akaike Information Criterion (AIC).

Figures 6.1 and 6.2 present the rolling VAR coefficients and confidence bands over the entire sample period employing the spliced ABX index and ABX 06-1 vintage

[1] Various alternative window widths have also been employed and the results do not change considerably.

AAA rated assets, respectively, as explanatory variables and the four aforementioned dependent variables. In order to conserve space lag one coefficients only are presented.[2]

[**Insert Figures 6.1 - 6.2 about here**]

These figures indicate that the coefficients are not stable over the 2006-2009 period. We observe very little movement in the coefficients prior to mid-2007, after which all become relatively volatile. This suggests that imposing the crisis regime to begin in January 2007, as in Longstaff (2010), may not be appropriate and provides motivation for further analysis.

6.4. Time-Varying Transition Probability Markov-Switching Vector Autoregressive (TVTP) Analysis

This chapter aims to analyse the effect of shocks to the subprime mortgage-backed securities market on different financial markets during the crisis of 2007-2009 following the framework outlined in Longstaff (2010). To this end, a VAR framework is appropriate. However, the results of the rolling VAR analysis presented above suggest that imposing a crisis regime to begin in January 2007 may not be realistic as coefficient behaviour remains relatively stable during early 2007.

We therefore employ a two-state Markov-switching VAR with time-varying transition probabilities, thus allowing regimes to be selected endogenously by the data. Two states are chosen due to the relatively short length of our data and the fact that academic literature analysing the crisis suggests once the U.S. real estate bubble burst in early 2007 markets remained in contraction until June 2009 (National Bureau of

[2]Full results are available on request.

Economic Research). Also, casual analysis of ABX index returns and the financial market variables suggest that two regression lines would better fit the data than one.[3] This is also backed up by the results of the rolling VAR analysis presented above.

In order to test for "a significant increase in cross-market linkages following a shock in one market", we include an ABX asset as an endogenous variable in the VAR framework to examine the relationship between this market and the other financial markets analysed. We include the AAA-rated asset because this tranche would have been the largest in the CDO structure (approximately 80%) and would have been the most liquid, particularly when the crisis hit. Should we observe a significant difference in the relationships between the ABX asset and the financial market variables once the system enters a crisis regime we can then conclude evidence of contagion, following our definition and framework.

This approach also requires the selection of an "information variable", i.e. a variable that determines the transition probability matrix for a switch in regime. As we are analysing contagion from the ABX market, this trigger should come from within the ABX assets. However, as we include the AAA-rated asset as an endogenous variable in the VAR we must select a variable outside of the system. We therefore choose the next highest rating, the AA-rated asset. Thus, our TVTP MS-VAR analysis includes the AAA-rated asset within the VAR model, with regime changes dependent upon the behaviour of lagged AA-rated asset returns.

The coefficients obtained depend upon the regime that the system is in at a particular

[3] See Figures 3.1 - 3.3 and Figure 4.1.

time. With two states we have:

$$Y_t = \begin{cases} (x_t)(b_1), s_t = 1 \\ \\ (x_t)(b_2), s_t = 2 \end{cases}, \tag{6.2}$$

in which s_t denotes the state of the system at time t and is determined by a Markov chain calculated from a transition matrix which groups the probabilities that one state is followed by another. The first set of coefficients applies to regime one while the second set applies to regime two. The data determine the probability of the regime being in a particular regime at a particular time.

6.4.1. Model Specification

Our model takes the form:

$$y_{i,t} = \alpha(s_t) + \sum_{k=1}^{2} \beta_k(s_t) y_{i,t-k} + \epsilon_{i,t}^{st}, \tag{6.3}$$

$$s_t \in \{1, 2\},$$

$$\epsilon_{i,t}^{st} \sim i.i.d.N(0, \sigma_{st}^2),$$

in which $y_{i,t}$ is an n dimensional time series vector of dependent variables, α is a matrix of state dependent intercepts, $\beta_1 \ . \ . \ . \ \beta_k$ are matrices of the state dependent autoregressive coefficients, $\epsilon_{i,t}^{st}$ is a state dependent noise vector and s_t is an unobserved random variable that causes the system to change from regime to another. We assume s_t follows a first-order Markov process in which the current regime, s_t relies only on the regime one period in the past, s_{t-1}. We therefore examine two discrete states, denoted as s_1 and s_2. s_1 represents a low-volatility, "non-crisis" regime while s_2 represents a high-volatility, "crisis" regime. Four lags were initially employed but, due to the highly nonlinear nature of the model and the relatively large number of coefficients to estimate, led to imprecise estimates and difficulty in converging to a global maximum. Three lags also led to this problem. Also, results obtained using three and four lags in the estimation were insignificant. We therefore employ a two lag model which, as we will show later, is sufficient to capture any serial correlation in this system.

In the fixed transition probability model, the regime follows a first order Markov-chain:

$$
\begin{aligned}
p[s_t = 1|s_{t-1} = 1] &= p_{11},\\
p[s_t = 2|s_{t-1} = 2] &= p_{22},\\
p[s_t = 2|s_{t-1} = 1] &= p_{12},\\
p[s_t = 1|s_{t-1} = 2] &= p_{21},
\end{aligned} \tag{6.4}
$$

in which p_{11} denotes the probability of the system remaining in state 1 at time t, given that the system was in state 1 at time t-1; p_{21} denotes the probability of the system switching to state 2 from state 1; p_{22} denotes the probability of the system remaining in state 2 at time t, given that the system was in state 2 at time t-1; p_{12} denotes the probability of the system switching to state 1 from state 2.

In order to allow the transition between regimes to depend upon the behaviour of the AA-rated ABX asset we employ the time-varying transition probability specification of Filardo (1994). As Filardo (1998) highlights, allowing the probability of switching from one regime to another to depend upon the behaviour of underlying fundamentals offers more flexibility than the fixed transition probability model and provides advantages such as capturing complex temporal persistence, allowing expected duration of a regime to vary across time and recognising systematic changes in the transition probabilities before and after turning points. In this case:

$$
\begin{aligned}
p[s_t = 1|s_{t-1} = 1] &= p_{11}(z_t), \\
p[s_t = 2|s_{t-1} = 2] &= p_{22}(z_t), \\
p[s_t = 2|s_{t-1} = 1] &= p_{12}(z_t), \\
p[s_t = 1|s_{t-1} = 2] &= p_{21}(z_t),
\end{aligned} \tag{6.5}
$$

in which z_t denotes our information variable, lagged ABX AA-rated asset weekly percentage returns.

The justification for including lagged ABX returns is outlined by Filardo (1998), which provides a set of sufficient conditions to justify the use of Hamilton's (1989) method for TVTP models. This is due to the fact that the inclusion of additional data, z_t, in the unconditional likelihood function implies the need to jointly estimate the parameters of the y and z processes. Conditional exogeneity between z_t and S_t validates Hamilton's (1989) approach for the TVTP model. As Filardo (1998) states: *"In general, the information variables that govern time-variation in the transition probabilities must be conditionally uncorrelated with the state of the Markov process"*. In this case z_{t-1} is considered to be predetermined with respect to S_t. Given y_1, z_1 is conditionally uncorrelated with S_1 and the conditional likelihood function is given by $\pi_\theta(z_1 \mid y_1, S_1) = \pi_\theta(z_1 \mid y_1)$. In other words ABX returns one period ago are considered to be predetermined with respect to the state of the system this period. We model the transition probabilities as a logistical functional form:

$$p(z_t) = \frac{exp(\theta_{p0} + \sum_{k=1}^{K_1} \theta_{pk} z_{t-k})}{1 + exp(\theta_{p0} + \sum_{k=1}^{K_1} \theta_{pk} z_{t-k})},$$
$$q(z_t) = \frac{exp(\theta_{q0} + \sum_{k=1}^{K_2} \theta_{qk} z_{t-k})}{1 + exp(\theta_{q0} + \sum_{k=1}^{K_2} \theta_{qk} z_{t-k})}. \quad (6.6)$$

The model is estimated using the Expectation Maximization (EM) algorithm presented by Hamilton (1990) in which we suppose $\{y_t\}_{t=1}^{T}$ is the sample path of a time series that depends on $\{s_t\}_{t=1}^{T}$ as follows:

$$(y_t \mid s_t = i; \alpha_i) \overset{iid}{\sim} N(\mu_i, \sigma_i^2), \quad (6.7)$$

where $\alpha_i = (\mu_i, \sigma_i^2)$, $i = 1, 2$. The density of y_t conditional upon s_t is:

$$f(y_t \mid s_t = i; \alpha_i) = \frac{1}{\sqrt{2\pi\sigma_i}} exp\left(\frac{-(y_t - \mu_i)^2}{2\sigma_i^2}\right). \quad (6.8)$$

Let $\theta = (\alpha', \beta', \rho)'$ be the vector of all model parameters. The complete-data log likelihood in terms of indicator functions may be expressed as:

$$\begin{aligned} logf(\underline{y}_T, \underline{s}_T \mid \underline{z}_T; \theta) = I(s_1 = 2)[logf(y_1 \mid s_1 = 2; \alpha_2) + log\rho] \\ +I(s_1 = 1)[logf(y_1 \mid s_1 = 1; \alpha_1) + log(1 - \rho)]) \\ + \sum_{t=2}^{T} \{I(s_t = 2)logf(y_t \mid s_t = 2; \alpha_2) + I(s_t = 1)logf(y_t \mid s_t = 1; \alpha_1) \\ +I(s_t = 2, s_{t-1} = 2)log(p_t^{22}) + I(s_t = 1, s_{t-1} = 2)log(1 - p_t^{22}) \\ +I(s_t = 2, s_{t-1} = 2)log(1 - p_t^{11}) + I(s_t = 1, s_{t-1} = 2)log(p_t^{11})\}, \quad (6.9) \end{aligned}$$

where f denotes any density and underlining denotes past history of the variable from

$t = 1$ to the variable subscript. As the complete data are not observed the complete-data log likelihood cannot be constructed in practice but the incomplete-data log likelihood may be obtained by summing over all possible state sequences:

$$logf(\underline{y}_T, | \underline{z}_T; \theta) = \left(log \sum_{s_1=1}^{2} \sum_{s_2=1}^{2} ... \sum_{s_T=0}^{2} f(\underline{y}_T, \underline{s}_T \mid \underline{z}_T; \theta) \right), \tag{6.10}$$

then maximise w.r.t θ. However, this is computationally intractable as $\{s_t\}_{t=1}^{T}$ may be realised in 2^T ways. We therefore follow EM algorithm for maximisation of the incomplete-data likelihood as proposed by Diebold et al. (1994).

6.4.2. Spliced ABX Index TVTP MS-VAR Results

Turning first to the spliced ABX index analysis, we plot the smoothed probabilities of the system being in a crisis regime. We calculate these probabilities as follows:

$$P(s_t = i | F_T; \theta), i = 1, 2, \tag{6.11}$$

in which F_T denotes the collection of all observed variables up to and including time T, in other words all information in the sample, and θ is the vector of parameters $(\alpha(st), \beta_k(st), \sigma^2_{st}, p_{11}, p_{22}, p_{12}, p_{21})$. Smoothed estimates are then computed via the backward recursion algorithm as presented by Kim (1994) and Hamilton (1994). Figure 6.3 illustrates the smoothed probabilities obtained from the spliced ABX index analysis.

[**Insert Figure 6.3 about here**]

These suggest that the watershed of regimes occurs mid-2007, with the crisis regime dominating thereafter until the end of the sample. This suggests that exogenously imposing the crisis regime to begin in January 2007, as in Longstaff (2010), may not be realistic. Furthermore, treating 2007 as a single period for analysis ignores the structural break that occurs midway through the year and thus may create problems for the original analysis. We observe a fall in these probabilities between July and September 2008, which may be an effect of splicing the data.

Our first task is to classify two regimes, a low-volatility non-crisis regime and a high-volatility crisis regime. Table 6.1 reports means and standard deviations for each variable in each regime, along with the coefficients on the transition probabilities. These coefficients can be viewed as a measure of persistence of a regime. Significant coefficients indicate that the regime under consideration is persistent, that is, it is highly likely that whatever state prevails at $t-1$ will prevail at t.

[**Insert Table 6.1 about here**]

The results reported in Table 6.1 indicate that two regimes are identifiable. The standard deviation of each variable increases following the switch in regimes, and standard deviations are statistically different from zero in regime two, the crisis regime. Also, significant coefficients on the indicated transition probabilities suggest that the crisis regime is persistent.

Table 6.1 reports that the ABX AAA-rated asset mean returns become increasingly negative after the regime switch, as expected. However, S&P 500 index mean returns actually increase. This may be due to the S&P 500 experiencing losses much later than the spliced ABX index. The Treasury spread mean falls slightly following the switch in regimes, indicating that this spread narrowed following the crisis. Intuitively this is not the result we expect, but the change is relatively small. The mean changes of the corporate spread become negative following the regime switch implying that this spread narrowed during the crisis and the VIX becomes negative in the crisis regime, indicating a decrease in this variable. These results suggest that, given the long duration of the ABX crisis, investors became optimistic about general market volatility and corporate bond markets earlier than they did about any potential recovery in the market for subprime mortgage-backed securities. Also, the crisis was not coincident across markets and so would have affected them at different times depending on market events.

As a preliminary analysis of how the relationship between the ABX asset and the financial market variables may have changed following the crisis, Table 6.2 reports the correlation coefficients between them in each regime.

[**Insert Table 6.2 about here**]

The correlation between the ABX asset and the S&P 500 index increases following the switch from a non-crisis to a crisis regime, as expected. Although the ABX asset is negatively correlated with each other financial market variable in both regimes, it becomes less so after the switch in regimes. This indicates that, although still negative, there was increase in the correlation between these assets once the crisis hit the system. However, as shown by Forbes & Rigobon (2002), an increase in correlation does not necessarily constitute contagion. We therefore examine the coefficients on the AAA-rated ABX variable in each of the indicated VAR equations in order to ascertain if there was any change in the relationships between these assets after the switch in regimes. Results are reported in Table 6.3. T-statistics are reported in parentheses.

[**Insert Table 6.3 about here**]

Following our definition of contagion as a significant change in cross-market linkages following a shock in one market we fail to reject the null hypothesis of no contagion based on the results presented in Table 6.3. None of the coefficients are statistically different from zero in either regime suggesting that the ABX had no significant effect on the financial market variables in either non-crisis or crisis times. This result is in direct contrast to that presented in Longstaff (2010) in that we find no evidence of any lead-lag relation between ABX returns and changes in the financial market variables analysed, no forecast power from the ABX and, thus, no evidence of price discovery. We do, however, find evidence of Granger-causality from some of the financial market variables to the spliced ABX index during the non-crisis period.[4] Specifically, stock market returns and changes in the VIX index Granger-cause subsequent returns in the spliced ABX index. These interdependencies then dissipate in the crisis regime, suggesting that these assets behaved independently during the turbulent period as investors exited the asset-backed security sector. This indicates that, as the crisis evolved from a subprime security-backed problem to a broader global crisis risks were propagated through other channels. Possible channels include real estate market and the asset-backed commercial paper (ABCP) market. It is likely that shocks were filtered through such markets before reaching the financial markets examined here, meaning that that risk transmission to these financial variables was not instantaneous.

Next, we perform the analysis using the ABX 06-1 vintage in order to ascertain if splicing the data could influence the results obtained.

[4] In order to conserve space these are not reported here. Full results are available on request.

6.4.3. ABX 06-1 Vintage TVTP MS-VAR Results

Figure 6.4 illustrates the smoothed probabilities of the system being in a crisis regime.

[**Insert Figure 6.4 about here**]

Again it is clear that the watershed of regimes occurs in mid-2007, with the risky regime dominating thereafter until the end of the sample. In comparison to Figure 6.3 these smoothed probabilities exhibit less spikes. This difference is probably due to the fact that the ABX 06-1 vintage is a continuous variable and so avoids the jumps induced by splicing the indexes together.

Next we classify a low-volatility non-crisis and a high-volatility crisis regime by analysing the volatility of the variables in each state. Table 6.4 reports means and standard deviations for each variable in each regime, along with the coefficients on the transition probabilities.

[**Insert Table 6.4 about here**]

As the standard deviation of each variable increases following the watershed of regimes we can easily identify a non-crisis and a crisis regime. Again, all crisis regime standard deviations are highly significant and the significant coefficients on the indicated transition probabilities suggest that the crisis regime is persistent.

Turning to the means of each variable in both regimes, Table 6.4 reports that, unsurprisingly, the mean returns of the AAA-rated ABX asset and the S&P 500 index both become negative in the crisis period. This is in contrast to the results presented for the spliced ABX index, in which the S&P index expected mean increases following the regime switch. This suggests that in the VAR system driven by changes in the actual traded ABX asset the S&P 500 index began to fall earlier than in that driven by the spliced ABX index asset, indicating differences between the two ABX series examined. The mean of the Treasury bond changes becomes positive following the watershed of regimes implying that this spread widened during the crisis as the difference between short- and long-term Treasury bonds increased. Again both the corporate spread and VIX mean changes become negative, although not statistically significant, pointing to investor sentiment regarding these markets improving earlier than that regarding the ABX market.

Table 6.5 reports that the correlation between the AAA-rated ABX asset and the other financial market variables in both regimes.

[**Insert Table 6.5 about here**]

The ABX asset becomes more correlated with the S&P 500 index and the corporate spread following the watershed of regimes. However, it becomes negatively correlated with both the VIX and the Treasury bill spread, suggesting that a fall in the ABX corresponds to an increase in changes in both the VIX and the government spread. Table 6.6 provides the coefficients on the AAA-rated ABX variable in the indicated VAR equations.

[**Insert Table 6.6 about here**]

Again, we observe no significant coefficients and so we fail to reject the null hypothesis of no contagion from the ABX 06-1 vintage to the financial market variables examined. As mentioned earlier this could be because the shocks were transmitted through different channels, such as the asset-backed commercial paper (ABCP) market, before reaching equity, Treasury, corporate bond and volatility markets. As in the spliced

ABX index analysis we find the stock market and volatility market measures Granger-cause ABX 06-1 vintage returns in the non-crisis regime, indicating that before the crisis hit these markets significantly affected the asset-backed security market. This is reasonable, given that during this time these assets were growing in popularity and were closely monitored by market participants as a means of gauging the subprime market risk and so had links with equity market conditions and general market volatility. During 2007, however, there is no evidence of linkages among the financial market variables and either ABX series. As the subprime crisis hit, investors began to rapidly reassess the risk of these products, subsequently exiting this market. Trades in these securities slowed down as concerns regarding counterparty risk increased and general market liquidity dried up. Risks from the ABX quickly became overshadowed by credit shortages and the ability of institutions to roll over debt. It is likely then that these risks transmitted to markets in a more rapid fashion than those emanating from the ABX. The ABX market is closely linked to the ABCP market and the real estate market so it is likely that these markets would have been negatively affected by its collapse sooner than the financial markets analysed here. Risk may then have filtered down to these markets through these channels.

Clearly, these results are in striking contrast to those obtained by Longstaff (2010). Firstly, we find no evidence of cross-market contagion. Also, many of the expected means and correlations are considerably different among the two data sets. Finally, the ex-post smoothed probabilities suggest that exogenously imposing a crisis regime to begin in January 2007 may not be appropriate. It is therefore important that we address why these differences may occur. Other than the clear differences between the the methodology employed in this chapter and that in Longstaff (2010), in the original application of the VAR Newey-West adjusted t-statistics were used in order to account for non-constant variances in each distinct period. In our framework, although the variances differ across the two regimes, they are constant within each regime itself, which may influence results.

As discussed above the spliced ABX index is a combination of the four ABX vintages, spliced together at each subsequent vintage issuance date. The dominant index is therefore the 07-2 vintage, which would be the riskiest of the four as it was issued in July 2007 and backed by loans originated in early 2007.[5] To investigate the difference between the spliced and traded results the differences in the ex-post smoothed probabilities of a crisis regime are calculated. These are illustrated in Figure 6.5.

[**Insert Figure 6.5 about here**]

A value of minus one indicates a point at which the spliced ABX index VAR system results report a zero probability of the system being in a crisis regime but the ABX 06-1 vintage system results report a probability of one. Figure 6.5 illustrates that between 2007 and 2008 a difference of this magnitude, or close to it, occurred numerous times. Based on the time line of the crisis it is not reasonable to assume that the system was not in a crisis regime at these points during this volatile period. This may be due to the introduction of the riskier ABX 07-1 and ABX 07-2 vintages into the spliced index during 2007. The assets underlying these riskier vintages would have been relatively illiquid during this time and it may be the halt in trading that occurred as investors and institutions were reassessing risks that causes this result.

As well as contrasting to the findings presented by Longstaff (2010), the results from the TVTP MS-VAR analysis are surprising, as they suggest that the financial markets examined experienced no interactions during the crisis regime. In order to investigate

[5]See Figure 2.7 for raw ABX prices.

this further we perform a number of robustness checks. Firstly, we perform several diagnostic tests on the standardized expected residuals from the above models. Secondly, we re-perform the TVTP MS-VAR analysis employing the BBB-rated ABX asset as an endogenous variable in an effort to ascertain if contagion many have emanated from this riskier asset. Finally, we perform trivariate TVTP MS-VAR analyses in order to address if the methodology, and in particular the dimensionality of our application, may have influenced the results.

6.5. Robustness Checks

6.5.1. Diagnostic Tests on Standardized Expected Residuals

Due to the state variable s_t, residuals are unobservable so we must calculate the standardized expected residuals. Following Maheu & McCurdy (2000) and using equation (6.3) these are calculated as follows:

$$\sum\nolimits_{s_t,\ldots s_{t-1}} \frac{Y_{i,t} - E[Y_{i,t}]|s_t,...,s_{t-1},Y_{i,t-1}}{\sigma(st)} P(s_t,...,st-1|Y_{t-1}). \tag{6.12}$$

Table 6.7 presents the results of diagnostic tests on these residuals.

[**Insert Table 6.7 about here**]

Columns 1 and 2 of Table 6.7 report the LM test for serial correlation in the standardized expected residuals of each variable examined in both analyses. For the majority of variables we cannot reject the null of no serial correlation at both one and four lags.

To test for Normality we use the Anderson-Darling test. Column 5 indicates that the majority of expected standardized residuals in the spliced ABX analysis are normally distributed but in most cases for the ABX 06-1 vintage analysis we reject normality. We find considerable evidence of ARCH effects at both lags one and four. Such a result suggests that an alternative approach, such as a switching ARCH model, may be more appropriate. However, given the relatively short time span of the data such a model may prove difficult to estimate. It should also be noted that, as Maheu & McCurdy (2000) point out, *"since we do not know the asymptotic distribution of the LB statistic using the standardized expected residuals, specification tests should be interpreted with caution."*

6.5.2. TVTP MS-VAR Analysis 2

In order to check the robustness of the above results the analysis is repeated with various ABX endogenous variables and various ABX information variables. Firstly, all other ABX assets are included in each analysis as an information variable in place of the AA-rated asset and the results do not change qualitatively. Next, the BBB-rated ABX asset is included as an endogenous variable in each analysis, in place of the AAA-rated asset.[6] Figure 6.6 illustrates the smoothed probabilities of the system being in a crisis regime for the spliced ABX index analysis.

[**Insert Figure 6.6 about here**]

These probabilities suggest that the watershed of regimes occurs in mid-2008, which is clearly an unexpected result, based on what we know regarding the evolution of

[6] The BBB- rated asset has also been included but, possibly due to stagnant prices during the crisis regime, provided imprecise estimates.

the crisis. As discussed above, the spliced ABX index is dominated by the ABX 07-2 vintage, the riskiest vintage, and so trading in the lower tranches of this index would have frozen once the crisis hit in 2007. This could possibly have caused the results presented in Figure 6.6. Table 6.8 reports the coefficients on the ABX variable in the indicated VAR equation.

[**Insert Table 6.8 about here**]

We again fail to reject the null hypothesis of no contagion as we observe no significant difference in the relationships between the ABX asset and the financial market variables. We also observe no persistence in the crisis regime.

Turning now to the ABX 06-1 vintage analysis, Figure 6.7 plots the smoothed probabilities of the system being in a crisis regime.

[**Insert Figure 6.7 about here**]

Comparing Figure 6.7 to Figure 6.6 the results appear to be more reasonable. We can identify the watershed of regimes as occurring in mid-2007, although the smoothed probabilities appear to spike more than those presented in the main analysis. Table 6.9 reports the coefficients on the ABX variable in the indicated VAR equation.

[**Insert Table 6.9 about here**]

We again observe no evidence to support contagion from the ABX to the financial market variables, however we do observe some persistence in the crisis regime. Overall these results indicate that our main analysis is robust.

6.5.3. Trivariate TVTP MS-VAR Analysis

Our results are unusual as they suggest that during the crisis regime all financial markets examined behaved independently, suggesting that the fact that they all experienced an increase in volatility and an increase in correlation with one another was coincidental. One reason we may observe such results could be a consequence of the large number of parameters in the model that require simultaneous estimation from a relatively short data set. A highly nonlinear model such as the TVTP MS-VAR model employed is extremely sensitive to the inclusion of many variables and lags (Manzan, 2004). Therefore, in an effort to reduce the dimensionality of the model, and to obtain clearer results, we employ one lag trivariate TVTP MS-VARs using the system presented in equation (6.3). We use every possible pair of financial market variables plus the AAA-rated ABX asset in the system, yielding six separate trivariate models for each ABX series. Tables 6.10 - 6.13 report the coefficients on the ABX variable in the indicated VAR equation for the spliced ABX index and ABX 06-1 vintage analyses.

[**Insert Tables 6.10 - 6.13 about here**]

In order to conserve space we do not present the means, standard deviations or smoothed probabilities.[7] However, as before, two regimes are easily identified as volatility increases once the system enters a crisis regime for every variable. Mean returns are also reasonable, for example S&P 500 mean returns become negative in the crisis regime. The crisis regime is also persistent in all estimations and the smoothed probabilities again suggest that the system entered a crisis regime in mid-2007.

Turning first to the spliced ABX index analyses, Tables 6.10 and 6.11 suggest that

[7] Full results are available on request.

there is some evidence of contagion from the ABX asset to the S&P 500 as ABX returns Granger-cause subsequent stock market returns in the crisis regime. However, the coefficients are statistically different from zero at only the 10% level. There is also evidence of significant linkages between U.S. Treasury and corporate debt markets in the crisis regime, which could be indicative of a "flight to quality" by investors.

Tables 6.12 and 6.13 also report evidence of contagion between government and corporate bond markets in the ABX 06-1 vintage analyses. There is also evidence of increased sensitivity to the ABX market in all other markets in the traded vintage analyses, although not present in each pair analysed.

These results again highlight the differences between the spliced and traded vintages and also shed some light on the observed differences in results between our original analyses and those reported in Longstaff (2010). They indicate that when the crisis is correctly identified there is indeed evidence of increased interactions between the financial markets analysed in the crisis regime, however this contagion is not as widespread as that suggested in Longstaff (2010). Again, this could be due to the timing of market events and contagion filtering down from markets more closely related to the asset-backed securities market to the financial markets examined, meaning we would not observe a link as direct as that reported in Longstaff (2010). The results we present are in fact more consistent with those reported in Longstaff (2010) for the "global-crisis" period of 2008, in which there is little evidence of contagion.[8] This suggests that the credit crisis led to decreased linkages between the ABX market and the other financial markets, as investors were rapidly exiting the asset-backed securities market and concerns were turning more toward liquidity.

In terms of methodology, the original application essentially ignored the structural

[8] See Table 5.6.

break that occurred in 2007, indicating that accurately dating the crisis is crucial to the analysis. Employing a four lag model, as in Longstaff (2010) and failing to take into account the structural break in mid-2007 could induce persistence in the model (Perron, 2006) causing the differences in results.

6.6. Conclusions

This chapter analyses contagion from the U.S. subprime mortgage-backed securities market by following and extending the VAR framework presented in Longstaff (2010). In order to do so we employ a Markov-switching VAR with time-varying transition probabilities. We apply the analysis to both the spliced ABX index employed by Longstaff (2010) and a traded ABX vintage, the ABX 06-1. The results allow us to determine a low-volatility non-crisis regime and a high-volatility crisis regime. We also determine, via ex-post smoothed probabilities of the system being in crisis regime, that the watershed of regimes occurs in mid-2007, with the risky regime dominating thereafter until the end of the sample. Our VAR analysis suggests that the ABX did not serve as a source of contagion to these markets during the 2007-2009 crisis, which is in striking contrast to the findings of Longstaff (2010).

In an effort to reduce the dimensionality of the model, and better capture contagion, we employ trivariate VAR analyses, the results of which yield some tentative evidence of contagion, although not as widespread as that reported by Longstaff (2010). Dating the crisis appears to be crucial, as in the original application the crisis period is an amalgamation of the tranquil start to 2007 followed by a turbulent second half. Again, breaking the crisis at the end of that year does not receive any support in our regime-switching model and in fact, our overall results are more in line with Longstaff's (2010) reported 2008 results in which there is little or no evidence of contagion.

Figure 6.1: Spliced ABX Index Rolling VAR Coefficients. Window width = 24. The solid black lines are point estimates; the dashed lines are confidence bands.

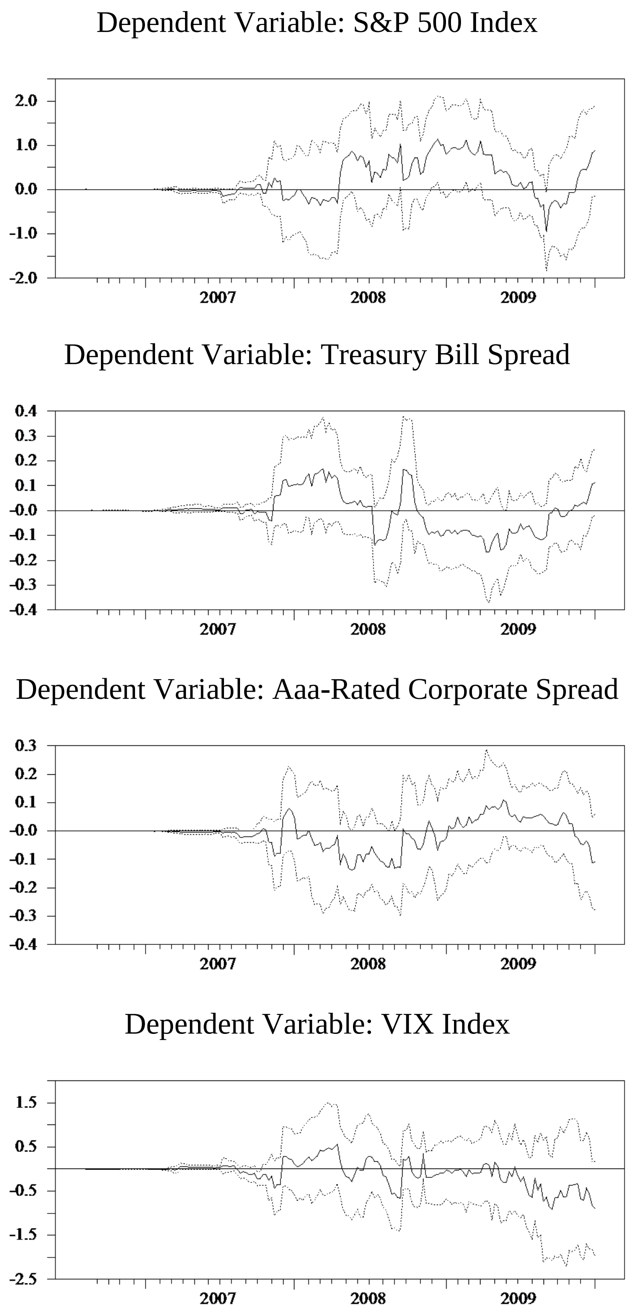


Figure 6.2: ABX 06-1 Vintage Rolling VAR Coefficients. Window width = 24. The solid black lines are point estimates; the dashed lines are confidence bands.

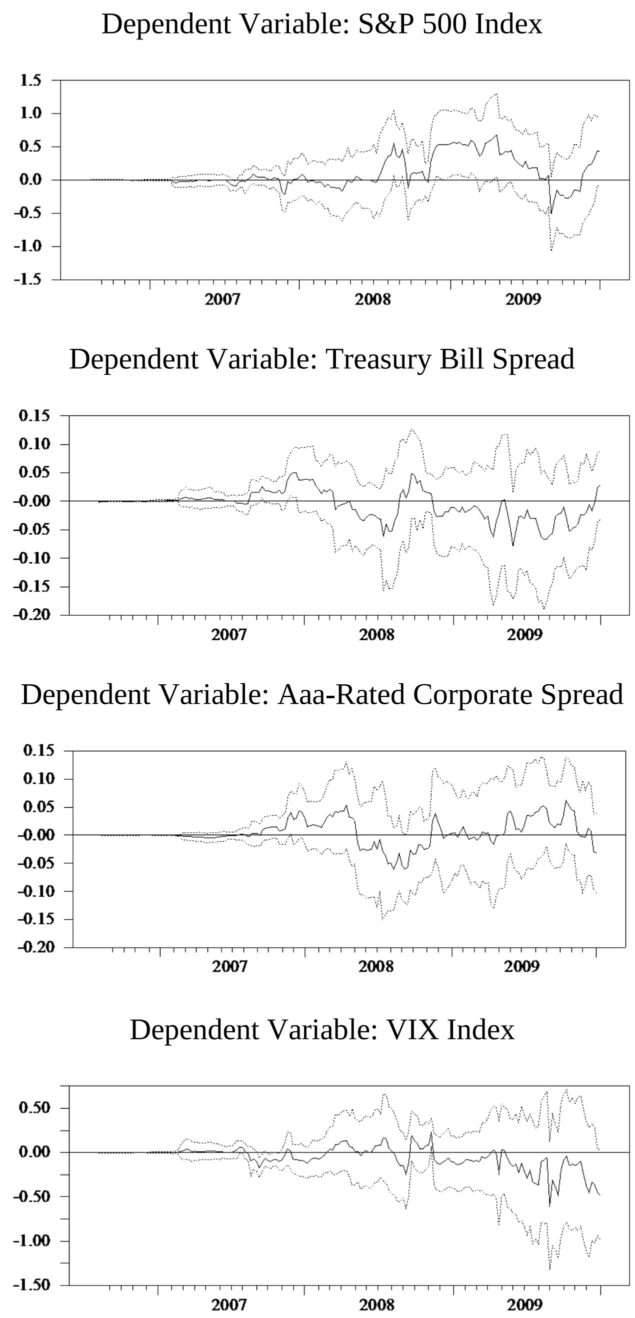


Figure 6.3: Spliced ABX Index TVTP MS VAR Smoothed Probabilities.

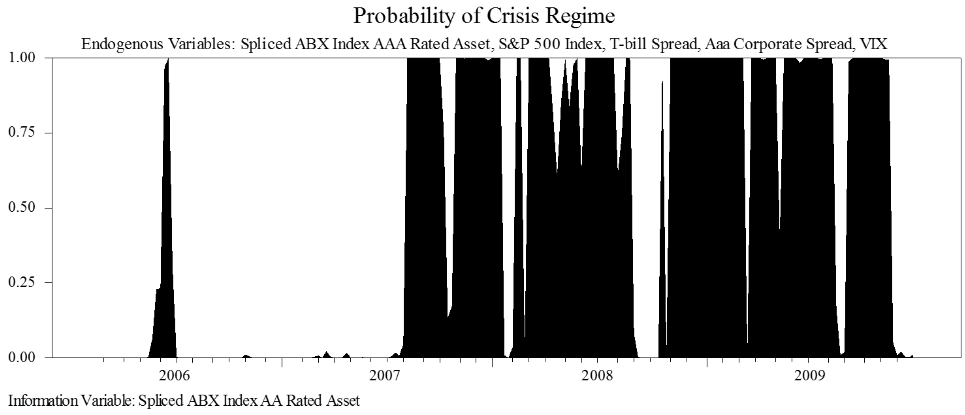


Figure 6.4: ABX 06-1 Vintage TVTP MS VAR Smoothed Probabilities.

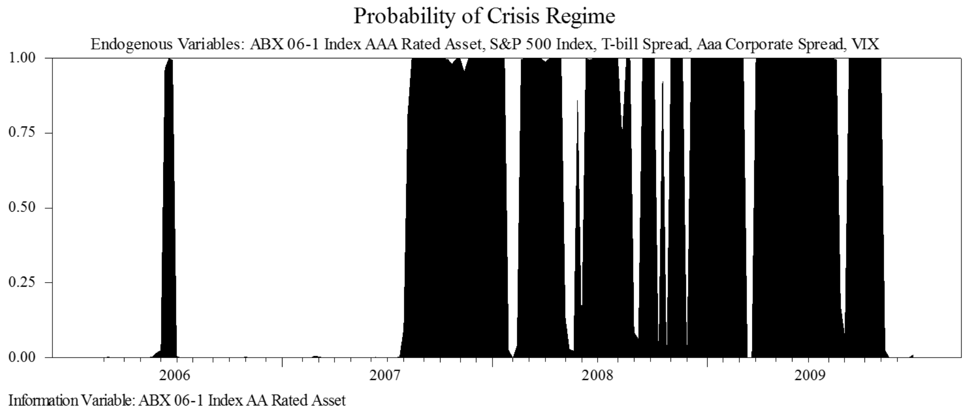


Figure 6.5: Smoothed Probabilities Differences.

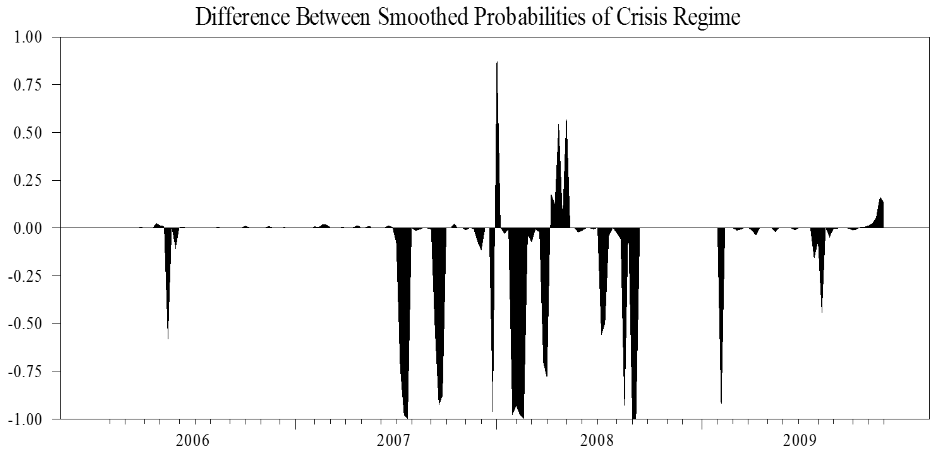


Figure 6.6: Spliced ABX Index TVTP MS VAR Smoothed Probabilities
Endogenous ABX variable: BBB asset.

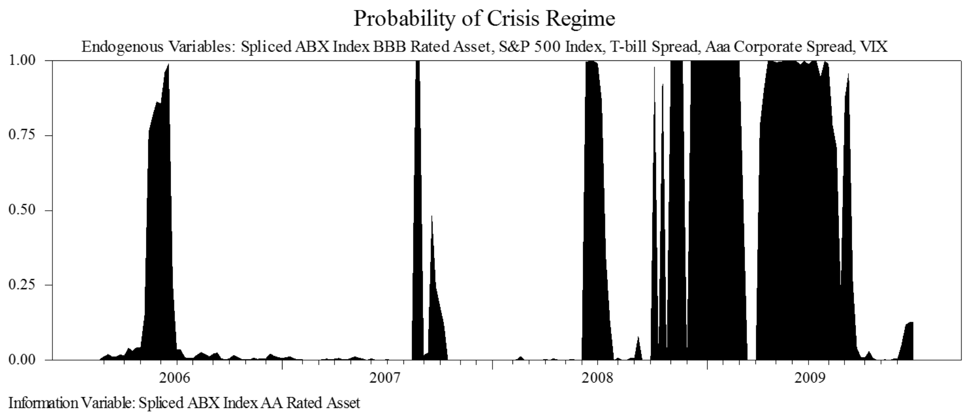


Figure 6.7: ABX 06-1 Vintage TVTP MS VAR Smoothed Probabilities
Endogenous ABX variable: BBB asset.

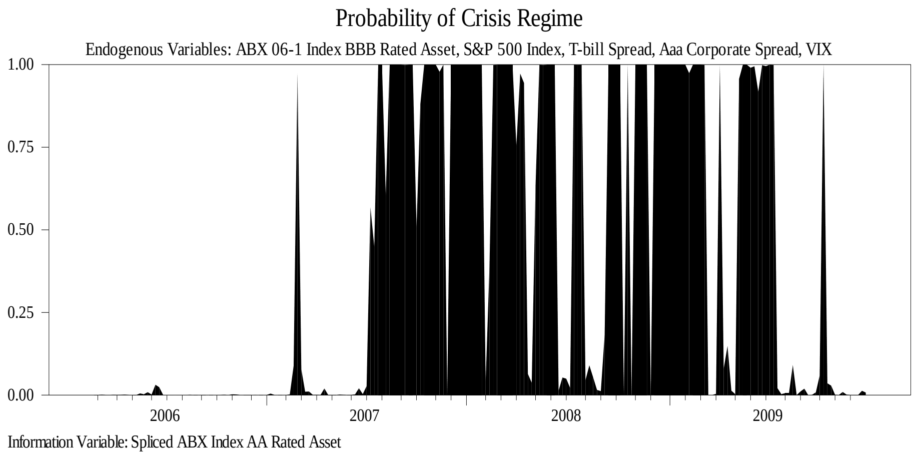


Table 6.1: Spliced ABX Index TVTP MS-VAR Estimation Results 1

Notes: This table reports means and standard deviations of the indicated variables in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly percentage returns, S& P 500 Index weekly percentage returns, weekly percentage changes in Treasury Bill spread, weekly percentage changes in Moody's Aaa corporate spread or weekly percentage changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset lagged weekly percentage returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level. θ denotes the coefficient on the indicated transition probability.

	Non-Crisis Regime		Crisis Regime	
	μ	σ	μ	σ
ABX AAA-rated Asset	-0.24	1.79	-0.58	6.01
	(-0.36)	(1.70*)	(-0.35)	(2.71**)
S&P 500 Index	0.09	1.97	0.26	2.87
	(0.14)	(1.68*)	(0.33)	(2.10**)
Treasury Bill Spread	1.91	8.45	1.81	15.27
	(0.97)	(2.24**)	(0.38)	(1.65*)
Aaa Corporate Spread	1.72	10.70	-2.40	15.90
	(0.44)	(1.44)	(-0.72)	(2.23**)
VIX Index	0.56	2.36	-0.95	3.58
	(0.70)	(1.75*)	(-0.92)	(1.70**)
		$\theta_{p1} = 2.23^{*}$	$\theta_{q1} = 2.73^{**}$	
		$\theta_{p2} = 0.34$	$\theta_{q2} = 0.05$	

Table 6.2: Spliced ABX Index TVTP MS-VAR Estimation Results 1

Notes: This table reports the correlation coefficients for the ABX AAA asset and the indicated variables in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly percentage returns, S& P 500 Index weekly percentage returns, weekly percentage changes in Treasury Bill spread, weekly percentage changes in Moody's Aaa corporate spread or weekly percentage changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset lagged weekly percentage returns.

	Non-Crisis Regime	Crisis Regime
$\rho_{AAA,S\&P500Index}$	0.57	0.57
$\rho_{AAA,TreasuryBillSpread}$	-0.22	-0.02
$\rho_{AAA,AaaCorporateSpread}$	-0.54	-0.16
$\rho_{AAA,VIXIndex}$	-0.61	-0.52

TABLE 6.3: Spliced ABX Index TVTP MS-VAR Estimation Results 1

Notes: This table reports the coefficients on the AAA ABX asset variable in the indicated financial market variable equation in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly percentage returns, S& P 500 Index weekly percentage returns, weekly percentage changes in Treasury Bill spread, weekly percentage changes in Moody's Aaa corporate spread or weekly percentage changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset lagged weekly percentage returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

	Non-Crisis Regime		Crisis Regime	
	β_1	β_2	β_1	β_2
S&P 500 Index	-0.35	-0.25	0.02	0.07
	(-1.01)	(-0.64)	(0.18)	(0.45)
Treasury Bill Spread	1.66	0.34	-0.48	0.47
	(0.94)	(0.19)	(-0.54)	(0.56)
Aaa Corporate Spread	-0.53	-0.63	0.12	-1.13
	(-0.31)	(-0.26)	(0.15)	(-1.19)
VIX Index	0.31	0.25	-0.01	-0.01
	(0.79)	(0.47)	(-0.05)	(-0.03)

Table 6.4: ABX 06-1 Vintage TVTP MS-VAR Estimation Results 1

Notes: This table reports means and standard deviations of the indicated variables in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly percentage returns, S& P 500 Index weekly percentage returns, weekly percentage changes in Treasury Bill spread, weekly percentage changes in Moody's Aaa corporate spread or weekly percentage changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset lagged weekly percentage returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level. θ denotes the coefficient on the indicated transition probability.

	Non-Crisis Regime		Crisis Regime	
	μ	σ	μ	σ
ABX AAA-rated Asset	-0.34	0.92	0.22	3.08
	(-0.89)	(2.11**)	(0.21)	(2.39**)
S&P 500 Index	0.47	1.58	-0.23	3.31
	(0.78)	(2.10**)	(-0.23)	(2.19**)
Treasury Bill Spread	-0.54	7.46	3.69	16.31
	(-0.16)	(1.46)	(0.75)	(2.10**)
Aaa Corporate Spread	1.49	8.44	-1.41	16.54
	(0.47)	(1.90*)	(-0.37)	(2.18**)
VIX Index	0.08	1.86	-0.53	4.13
	(0.12)	(2.49**)	(-0.41)	(2.61**)
		$\theta_{p1} = 2.27^*$	$\theta_{q1} = 2.90^*$	
		$\theta_{p2} = 0.74$	$\theta_{q2} = 0.07$	

TABLE 6.5: ABX 06-1 Vintage TVTP MS-VAR Estimation Results 1

Notes: This table reports the correlation coefficients for the ABX AAA asset and the indicated variables in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly percentage returns, S& P 500 Index weekly percentage returns, weekly percentage changes in Treasury Bill spread, weekly percentage changes in Moody's Aaa corporate spread or weekly percentage changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset lagged weekly percentage returns.

	Non-Crisis Regime	Crisis Regime
$\rho_{AAA,S\&P500Index}$	-0.25	0.52
$\rho_{AAA,TreasuryBillSpread}$	0.49	-0.02
$\rho_{AAA,AaaCorporateSpread}$	-0.45	-0.22
$\rho_{AAA,VIXIndex}$	0.15	-0.36

Table 6.6: ABX 06-1 Vintage TVTP MS-VAR Estimation Results 1

Notes: This table reports the coefficients on the AAA ABX asset variable in the indicated financial market variable equation in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly percentage returns, S& P 500 Index weekly percentage returns, weekly percentage changes in Treasury Bill spread, weekly percentage changes in Moody's Aaa corporate spread or weekly percentage changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset lagged weekly percentage returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

	Non-Crisis Regime		Crisis Regime	
	β_1	β_2	β_1	β_2
S&P 500 Index	-0.54	0.13	-0.12	0.01
	(-0.63)	(0.13)	(-0.30)	(0.02)
Treasury Bill Spread	1.13	-1.65	-0.47	0.79
	(0.24)	(-0.39)	(-0.27)	(0.45)
Aaa Corporate Spread	-4.34	-1.37	0.40	-1.16
	(-0.82)	(-0.34)	(0.21)	(-0.52)
VIX Index	0.11	-0.21	0.27	0.07
	(0.08)	(-0.19)	(0.59)	(0.14)

TABLE 6.7: Diagnostic Tests On Standardized Expected Residuals

Notes: LM(k) is the Breusch-Godfrey Lagrange Multiplier test for no serial correlation up to lag k, ARCH(k) is the Lagrange Multiplier test for the ARCH effects of order k, Normality is the Anderson-Darling test for the null of normality. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

Spliced ABX Index Analysis					
Variable	LM(1)	LM(4)	ARCH(1)	ARCH(4)	Normality
ABX AAA-rated Asset	0.04	2.72*	16.16**	9.32**	5.63**
S&P 500 Index	0.05	0.43	4.66**	3.61*	1.30
Treasury Bill Spread	1.40	1.43	3.69*	2.45*	1.89
Aaa Corporate Spread	0.29	0.01	0.04	3.70**	0.98
VIX Index	0.06	0.05	8.01**	8.67**	1.57
ABX 06-1 Vintage Analysis					
Variable	LM(1)	LM(4)	ARCH(1)	ARCH(4)	Normality
ABX AAA-rated Asset	0.90	8.03**	3.79*	5.65*	6.61**
S&P 500 Index	0.13	3.08*	1.35	0.62	3.58**
Treasury Bill Spread	2.15	0.30	0.87	4.34**	2.58**
Aaa Corporate Spread	0.02	0.75	4.72**	6.46**	1.17
VIX Index	0.12	0.02	2.66	8.18**	4.13**

Table 6.8: Spliced ABX Index TVTP MS-VAR Estimation Results 2

Notes: This table reports the coefficients on the BBB ABX asset variable in the indicated financial market variable equation in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly percentage returns, S& P 500 Index weekly percentage returns, weekly percentage changes in Treasury Bill spread, weekly percentage changes in Moody's Aaa corporate spread or weekly percentage changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset lagged weekly percentage returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

	Non-Crisis Regime		Crisis Regime	
	β_1	β_2	β_1	β_2
S&P 500 Index	-0.02	0.13	0.07	-0.15
	(-0.17)	(0.90)	(0.01)	(-0.03)
Treasury Bill Spread	0.10	-0.07	1.18	0.11
	(0.15)	(-0.11)	(0.04)	(0.01)
Aaa Corporate Spread	0.19	-0.26	-0.34	-0.35
	(0.33)	(-0.44)	(-0.01)	(-0.01)
VIX Index	0.02	-0.14	0.14	0.19
	(0.13)	(-1.15)	(0.02)	(0.04)
		θ_{p1} = 1.57	θ_{q1} = 0.03	
		θ_{p2} = -0.05	θ_{q2} = 2.56	

TABLE 6.9: ABX 06-1 Vintage TVTP MS-VAR Estimation Results 2

Notes: This table reports the coefficients on the BBB ABX asset variable in the indicated financial market variable equation in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{2} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly percentage returns, S& P 500 Index weekly percentage returns, weekly percentage changes in Treasury Bill spread, weekly percentage changes in Moody's Aaa corporate spread or weekly percentage changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset lagged weekly percentage returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

	Non-Crisis Regime		Crisis Regime	
	β_1	β_2	β_1	β_2
S&P 500 Index	-0.16	0.09	0.04	-0.02
	(-0.76)	(0.60)	(0.09)	(-0.04)
Treasury Bill Spread	0.42	-0.14	0.36	-0.06
	(0.47)	(-0.17)	(0.12)	(-0.04)
Aaa Corporate Spread	0.06	-0.10	-0.46	-0.29
	(0.05)	(-0.10)	(-0.20)	(-0.17)
VIX Index	0.14	-0.05	-0.02	-0.01
	(0.68)	(-0.39)	(-0.03)	(-0.01)
		$\theta_{p1} = 1.55^{**}$	$\theta_{q1} = 2.07^{**}$	
		$\theta_{p2} = 0.16$	$\theta_{q2} = 0.02$	

Table 6.10: Spliced ABX Index Trivariate VAR Estimation Results 1

Notes: This table reports the coefficients on the AAA ABX asset variable in the indicated financial market variable equation in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{1} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly percentage returns, S& P 500 Index weekly percentage returns, weekly percentage changes in Treasury Bill spread, weekly percentage changes in Moody's Aaa corporate spread or weekly percentage changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset lagged weekly percentage returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

VAR Variables: ABX AAA-rated Asset, S&P 500 Index, Aaa Corporate Spread			
Dependent	Independent	Non-Crisis β	Crisis β
ABX AAA-rated asset	S&P 500 Index 500	0.00	0.18
		(0.86)	(1.16)
	Aaa Corporate Spread	0.00	0.01
		(0.48)	(0.48)
S&P 500 Index	ABX AAA-rated Asset	-0.96	-0.08
		(-0.13)	(-1.50)
	Aaa Corporate Spread	-0.02	-0.01
		(-0.72)	(-0.98)
Aaa Corporate Spread	ABX AAA-rated Asset	-5.79	0.15
		(-0.06)	(0.48)
	S&P 500 Index	-0.02	-0.29
		(-0.72)	(-0.55)
VAR Variables: ABX AAA-rated Asset, S&P 500 Index, VIX Index			
Dependent	Independent	Non-Crisis β	Crisis β
ABX AAA-rated Asset	S&P 500 Index	0.00	0.56^{**}
		(0.38)	(2.16)
	VIX Index	0.00	0.40^{**}
		(0.42)	(2.33)
S&P 500 Index	ABX AAA-rated Asset	0.01	-0.10^{*}
		(0.01)	(-1.74)
	VIX Index	0.07	0.15^{*}
		(0.23)	(1.90)
VIX Index	ABX AAA-rated Asset	-0.13	0.13
		(-0.04)	(1.62)
	S&P 500 Index	0.22	-0.23
		(0.62)	(-1.36)
VAR Variables: ABX AAA-rated Asset, S&P 500 Index, Treasury Bill Spread			
Dependent	Independent	Non-Crisis β	Crisis β
ABX AAA-rated Asset	S&P 500 Index	0.00	0.16
		(0.79)	(1.00)
	Treasury Bill Spread	-0.00	0.01
		(-1.11)	(0.26)
S&P 500 Index	ABX AAA-rated Asset	2.25	-0.10^{*}
		(0.37)	(-1.66)
	Treasury Bill Spread	0.02	0.00
		(0.44)	(0.01)
Treasury Bill Spread	AAA	48.80	0.05
		(0.77)	(0.13)
	S&P 500 Index	0.02	-0.27
		(0.03)	(-0.56)

Table 6.11: Spliced ABX Index Trivariate VAR Estimation Results 2

Notes: This table reports the coefficients on the AAA ABX asset variable in the indicated financial market variable equation in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{1} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly percentage returns, S& P 500 Index weekly percentage returns, weekly percentage changes in Treasury Bill spread, weekly percentage changes in Moody's Aaa corporate spread or weekly percentage changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset lagged weekly percentage returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

VAR Variables: ABX AAA-rated Asset, Treasury Bill Spread, VIX Index			
Dependent	Independent	Non-Crisis β	Crisis β
ABX AAA-rated Asset	Treasury Bill Spread	-0.00	-0.01
		(-0.04)	(-1.54)
	VIX Index	0.08	0.01
		(0.60)	(-0.79)
Treasury Bill Spread	ABX AAA-rated Asset	-0.03	9.98*
		(-0.09)	(1.82)
	VIX Index	-0.01	-0.02
		(-0.03)	(-0.35)
VIX Index	ABX AAA-rated Asset	0.10	5.49
		(1.29)	(0.67)
	Treasury Bill Spread	-0.01	0.33
		(-0.03)	(0.44)
VAR Variables: ABX AAA-rated Asset, VIX Index, Aaa Corporate Spread			
Dependent	Independent	Non-Crisis β	Crisis β
ABX AAA-rated Asset	VIX Index	-0.01	0.07
		(-0.79)	(0.67)
	Aaa Corporate Spread	0.00	0.01
		(0.31)	(0.25)
VIX Index	ABX AAA-rated Asset	-2.03	0.13*
		(-0.28)	(1.69)
	Aaa Corporate Spread	0.02	0.02
		(0.86)	(1.34)
Aaa Corporate Spread	ABX AAA-rated Asset	-12.07	0.06
		(-0.25)	(0.18)
	VIX Index	0.22*	0.66**
		(1.79)	(3.52)
VAR Variables: ABX AAA-rated Asset, Treasury Bill Spread, Aaa Corporate Spread			
Dependent	Independent	Non-Crisis β	Crisis β
ABX AAA-rated Asset	Treasury Bill Spread	-0.00	0.01
		(-0.95)	(0.37)
	Aaa Corporate Spread	0.00	0.01
		(0.05)	(0.47)
Treasury Bill Spread	ABX AAA-rated Asset	-0.68	0.16
		(-0.09)	(0.53)
	Aaa Corproate Spread	-0.02	0.22**
		(-0.21)	(2.11)
Aaa Corporate Spread	ABX AAA-rated Asset	-5.63	0.04
		(-0.15)	(0.13)
	Treasury Bill Spread	0.69**	0.22*
		(3.66)	(1.76)

Table 6.12: ABX 06-1 Vintage Trivariate VAR Estimation Results 1

Notes: This table reports the coefficients on the AAA ABX asset variable in the indicated financial market variable equation in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{1} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly percentage returns, S& P 500 Index weekly percentage returns, weekly percentage changes in Treasury Bill spread, weekly percentage changes in Moody's Aaa corporate spread or weekly percentage changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset lagged weekly percentage returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

VAR Variables: ABX AAA-rated Asset, S&P 500 Index, VIX Index			
Dependent	Independent	Non-Crisis β	Crisis β
ABX AAA-rated Asset	S&P 500 Index	-0.06^{**}	0.51^{**}
		(-5.84)	(3.33)
	VIX Index	-0.03^{**}	0.35^{**}
		(-3.82)	(2.69)
S&P 500 Index	ABX AAA-rated Asset	0.94	-0.25
		(1.41)	(-1.52)
	VIX Index	-0.11	0.16
		(-1.20)	(1.60)
VIX Index	ABX AAA-rated Index	-0.48	0.32^{**}
		(-0.43)	(2.70)
	S&P 500 Index	0.57^{*}	-0.27
		(2.44)	(-1.37)
VAR Variables: ABX AAA-rated Asset, S&P 500 Index, Treasury Bill Spread			
Dependent	Independent	Non-Crisis β	Crisis β
ABX AAA-rated Asset	S&P 500 Index	0.18	-0.05^{**}
		(1.21)	(-3.60)
	Treasury Bill Spread	0.00	0.01^{**}
		(0.08)	(4.41)
S&P 500 Index	ABX AAA-rated Asse	-0.19	3.57^{**}
		(-1.25)	(2.43)
	Treasury Bill Spread	-0.00	0.05^{**}
		(-0.12)	(3.15)
Treasury Bill Spread	ABX AAA-rated Asset	-0.01	3.57^{**}
		(-0.01)	(2.43)
	S&P 500 Index	-0.55	0.06
		(-0.58)	(0.12)
VAR Variables: ABX AAA-rated Asset, S&P 500 Index, Aaa Corporate Spread			
Dependent	Independent	Non-Crisis β	Crisis β
ABX AAA-rated Asset	S&P 500 Index	0.00	0.15
		(1.23)	(1.52)
	Aaa Corporate Spread	0.00	0.01
		(0.33)	(0.43)
S&P 500 Index	ABX AAA-rated Asset	-0.53	-0.11
		(-0.09)	(-0.75)
	Aaa Corporate Spread	-0.02	-0.01
		(-0.79)	(-0.94)
Aaa Corporate Spread	ABX AAA-rated Asset	-1.20	0.34
		(-0.04)	(0.42)
	S&P 500 Index	0.40	-0.15
		(0.39)	(-0.26)

Table 6.13: ABX 06-1 Vintage Trivariate VAR Estimation Results 2

Notes: This table reports the coefficients on the AAA ABX asset variable in the indicated financial market variable equation in the non-crisis and crisis regimes estimated from the following TVTP MS-VAR specification:

$$y_{it} = \alpha(S_t) + \sum_{k=1}^{1} \beta_k(S_t) y_{it-k} + \epsilon_{it}^{st},$$

in which y_t denotes the financial market variable included as a dependent variable (ABX AAA asset weekly percentage returns, S& P 500 Index weekly percentage returns, weekly percentage changes in Treasury Bill spread, weekly percentage changes in Moody's Aaa corporate spread or weekly percentage changes in VIX Index). The information variable triggering a change in regime in the above estimation is ABX AA asset lagged weekly percentage returns. T-statistics are reported in parenthesis. The subscript ** denotes significance at the 5% level; the subscript * denotes significance at the 10% level.

VAR Variables: ABX AAA-rated Asset, Treasury Bill Spread,VIX Index			
Dependent	Independent	Non-Crisis β	Crisis β
ABX AAA-rated Asset	Treasury Bill Spread	-0.00^{*}	0.02
		(-1.70)	(0.17)
	Treasury Bill Spread	-0.00	0.04
		(-0.67)	(0.03)
Treasury Bill Spread	ABX AAA-rated Asset	13.74	-6.19
		(0.41)	(-0.21)
	VIX Index	0.43	-0.97
		(1.09)	(-0.17)
VIX Index	ABX AAA-rated Asset	-0.85	-2.91
		(-0.08)	(-0.89)
	Treasury Bill Spread	-0.03	-0.08
		(-0.62)	(-0.50)
VAR Variables: ABX AAA-rated Asset, VIX Index, Aaa Corporate Spread			
Dependent	Independent	Non-Crisis β	Crisis β
ABX AAA-rated Asset	VIX Index	0.00	0.01
		(0.79)	(0.37)
	Aaa Corporate Spread	-0.00	0.01
		(-0.91)	(0.20)
VIX Index	ABX AAA-rated Asset	-8.26	0.20
		(-0.47)	(0.31)
	Aaa Corporate Spread	-0.00	0.01
		(-0.91)	(0.20)
Aaa Corporate Spread	ABX AAA-rated Asset	-0.52	0.30^{**}
		(-0.16)	(2.59)
	VIX Index	-0.67	0.36
		(-0.72)	(0.85)
VAR Variables: ABX AAA-rated Asset, Aaa Corporate Spread, Treasury Bill Spread			
Dependent	Independent	Non-Crisis β	Crisis β
ABX AAA-rated Asset	Aaa Corporate Spread	0.01	0.01
		(0.17)	(0.26)
	Treasury Bill Spread	-0.01	0.23^{*}
		(-0.95)	(1.68)
Aaa Corporate Spread	ABX AAA-rated Asset	-2.05	0.37
		(-0.16)	(0.41)
	Treasury Bill Spread	0.75^{**}	0.23^{*}
		(4.00)	(1.68)
Treasury Bill Spread	ABX AAA-rated Asset	2.12	-0.63
		(0.11)	(-0.72)
	Treasury Bill Spread	-0.03	0.20^{*}
		(-0.28)	(1.69)

Chapter 7

Concluding Remarks

7.1. Overview of Thesis

This thesis focuses on three topical issues in relation to the financial crisis of 2007-2009, undertaking a thorough empirical investigation of these issues by examining what became the focal point of the crisis, the U.S. subprime mortgage-backed securities market, as represented by its only available proxy, the ABX.HE indexes.

Understanding the recent crisis and what led to its development and transmission is of central importance to financial institutions, policy makers and investors worldwide. As a consequence of a growing literature attempting to shed light on the subject we empirically examine the risk underlying the ABX indexes, and how this risk evolved over the crisis. We analyse contagion within this market, and the persistence of any shocks observed. Finally, we investigate how risk may have transmitted from this market to other asset markets by testing for contagion from the ABX to several fixed income, equity and volatility markets during the crisis.

Chapter 2 provides a comprehensive overview of the crisis and what led to it, including a description of the ABX indexes that are the focus of this thesis.

Chapter 3 analyses risk factors underlying the ABX indexes and how these may have changed over the duration of the crisis. The analysis yields some interesting results. Firstly, it is suggested that the ABX indexes are distinct in their vintage, subject to different risk profiles, consistent with Dungey, Dwyer & Flavin (2013). Secondly, clear differences also emerge between the different ratings classes comprising the indexes, indicating that they were affected differently by risk factors over the crisis, a result that corresponds to that presented by Fender & Scheicher (2008). Finally, the results allow us to observe how the importance of risk factors changed as the crisis evolved from the real estate sector to impact credit markets and market-wide liquidity. For investors and institutions trading these products these results suggest that they should be treated as heterogeneous assets, and not simply as a continuation of the previous issuance. For policy makers it suggests that the risk of the assets underlying each index should be carefully assessed independently of other vintages. It also highlights the importance of assessing links that may exist between different players in financial markets, and perhaps improving stress testing to better assess what losses may occur should one of those players default.

Chapter 4 tests for contagion within the ABX indexes, following and modifying the VAR framework outlined by Longstaff (2010), to better understand these complex securities. The spliced ABX index employed by Longstaff (2010) is analysed, along with two traded vintages. Our results reveal further interesting facts regarding the U.S. subprime mortgage-backed securities market. Firstly, we observe evidence of contagion within the three ABX series during the subprime crisis period of 2007. Secondly, contagion emanates mainly from the higher-rated assets in the traded vintages. Finally, any persistent shocks originate in the higher-rated assets in the traded vintages but the lower-rated assets in the spliced index. This again highlights the heterogeneous nature of the traded indexes, and also suggests considerable differences between the traded vintages and spliced index. For institutions and investors trading these tranched assets it suggests that, once the common shock hit the system, risk transmitted from the lower- to higher-rated assets, as described in Coval, Jubak & Stafford (2009), causing the latter to be hit by massive losses also. This indicates that the ratings of these products essentially did not matter once the crisis occurred. From a policy perspective it highlights the need for more stringent regulation regarding the construction of such securities, and particularly in terms of how they are rated, to halt the migration of risk in such a way.

Chapter 5 investigates contagion from the ABX indexes to several fixed income, equity and volatility markets during the crisis, again following the VAR framework employed by Longstaff (2010), applying the analysis to two traded vintages. Our results are broadly in line with the original study with evidence of widespread contagion to the financial markets analysed during the 2007 "subprime-crisis" period, which then dissipates in the 2008 "global-crisis" period as liquidity came to a halt, before increasing slightly in 2009 as markets rebounded. However, this application requires regimes to be imposed exogenously on the data so, in an effort to develop a more appropriate approach to the question, the methodology is extended in Chapter 6.

Therefore Chapter 6 re-examines the issue of contagion from the subprime mortgage-backed securities sector of the financial system by employing a more suitable econometric technique. Specifically we employ time-varying transition probability Markov-switching properties in order to allow regimes to be imposed endogenously by the data. The results provide some interesting facts regarding the crisis and the role that the ABX played in it. Firstly, we find that the watershed of regimes occurs in mid-2007, with the risky regime dominating thereafter until the end of the sample. Secondly, although we do observe some evidence of contagion in the crisis regime, that contagion is not as widespread as reported by Longstaff (2010). This implies that accurately timing the onset of the crisis is crucial to the analysis. We conclude that this result may be observed due to markets more closely related to the ABX, such as the ABCP market, being affected by shocks sooner than those examined in this chapter, and then transmitting those shocks to other markets. For academics, these results highlight the importance of taking account of structural breaks that may occur in data when performing similar analyses. Failure to do so can lead to employing high-order autoregressive processes, thus over-estimating persistence, and influencing conclusions. In terms of the subprime mortgage-backed securities sector, they indicate that, once real estate concerns became overshadowed by concerns regarding liquidity and counterparty risk and investors began rapidly exiting the ABS market, the ABX indexes were not a strong source of contagion to the financial markets examined.

7.2. Future Research

This thesis presents a number of possible avenues for future research. Firstly, in order to investigate the question of contagion from the ABX indexes further, a number of different channels of contagion could be investigated. Longstaff (2010) also approaches this issue by analysing contagion from the ABX to several proxies for liquidity, namely changes in the aggregate amount of ABCP outstanding, the total weekly value of settlement failures by primary dealers in Treasury, agency, mortgage and corporate bond markets and the weekly ratio of trading volume for the S&P 500 subindex of financial firms to the total trading volume for the S&P 500 index. It may be interesting to incorporate these variables in our TVTP MS-VAR model to examine contagion from the ABX market to these liquidity variables.

There are also a number of alternative methodologies regarding contagion and price discovery from the ABX market to other financial markets such as the conditional correlation method presented by Forbes & Rigobon (2002) and a switching ARCH model. These alternatives may better account for the conditional heteroscedasticity in the system but the trade-off will be their inability to deal with large numbers of financial assets.

As it is possible that contagion may have been more widespread among markets more closely related to the ABX market before affecting the financial markets examined in this thesis it may also be useful to extend our analysis to include the ABCP market and other types of ABS markets to further investigate this issue.

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